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Cockpit Task Management (CTM) is the initiation, monitoring, prioritization, execution, and termination of multiple, concurrent tasks by flight crews. The primary research question posed in the current research is what factors affect task prioritization on the modern day, commercial flight deck. The conventional CTM literature was reviewed as an introduction to CTM validation, its facilitation and its theoretical foundations. A human performance approach to CTM was explored through experimental psychology literature, with the objective of developing a deeper understanding of the prioritization process. Two experimental part-task simulator studies were performed using commercial airline pilots. The objective of the first study was to simply identify possible prioritization factors. The second study then gathered empirical evidence for actual use of these factors. From the results, a model of task prioritization emerged with ***Status***, ***Procedure*** and ***Value*** as the primary factors that affect task prioritization.

Factors That Affect Task Prioritization on the Flight Deck

by

Kurt W. Colvin

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Kurt W. Colvin, Author

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There is one indisputable fact: I was the one who performed the research contained in these pages. With that said, I could not have accomplished this task without the help and support of many people, just a few of whom I will explicitly acknowledge.

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basketball player, politician and author once said, "I can tell more about the character of a person by playing 3-on-3 with them for 20 minutes, than I can by talking to them for a year."

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CHAPTER 1:

INTRODUCTION

The present research investigates the factors that affect task prioritization on the flight deck of commercial, transport aircraft. The theoretical foundations of the investigation of human behaviors in a multiple, concurrent task environments lie in the general research area known as Task Management (TM). Research efforts over the past decade have studied aviation domains specifically, and this area is known as Cockpit Task Management (CTM).

The scope of the present work begins with a review of existing literature related to CTM, presented in Chapter 2. Chapter 3 approaches CTM not from an engineering, system-based approach, as was done in the past, but rather from a human performance-based approach, reviewing experimental psychology literature regarding how humans perform and manage multiple, concurrent tasks. From Chapter 3, a fundamental research question emerges: What are the factors that affect task prioritization?

Chapter 4 documents an initial experimental study that had the objective of identifying the possible factors that influence task prioritization in the operational context of a commercial aircraft flight deck. The study was performed in a part-task flight simulator using commercial airline pilots as subjects. The data collected in Chapter 4 suggests 12 possible factors that emerged as candidates for prioritization factors used by pilots on the flight deck. These 12 factors were used to develop a theoretical model of factors that affect task prioritization.

Chapter 5 documents a second experimental study that begins with the model of task prioritization with the objective of collecting data to support the actual use of the proposed factors. From this data, conclusions were drawn suggesting new knowledge has been discovered regarding how humans prioritize multiple tasks on the flight deck.

Finally, Chapter 6 is a summary, bringing together the key points and findings explored throughout the entire project.

CHAPTER 2:
COCKPIT TASK MANAGEMENT: LITERATURE REVIEW

Introduction

During the late 1990s, there is evidence that air travel is, statistically speaking, a very safe form of transportation. However, this was not always the case. In the 1950s, when commercial jet transport was introduced, the worldwide accident rate approached 30 accidents per million departures. By the end of 1997, that rate has dropped to approximately 1.4 accidents per million departures (Boeing, 1998).

This decrease can be attributed to improved aircraft technologies, improved air traffic control (ATC), industry infrastructure, operations and maintenance procedures, training and regulations. Although these improvements are significant, and the accident rate is relatively low, it has been stable for approximately the last 20 years. The leveling of the accident rate has occurred despite innovations like improved computerized flight simulators, expanded radar coverage, high-tech devices that warn pilots of nearby aircraft, proximity to terrain, precarious aircraft altitude, and hazardous weather and wind-shear conditions. It is sobering to realize that if Boeing's and Airbus's worldwide aviation traffic growth projections of 5%, compounded annually, are accurate, one major accident will occur ***each week*** by 2014 (Flight Safety Foundation, 1998).

The aviation industry strives for continuous safety improvements through many channels, including better pilot training, better aircraft inspection and maintenance techniques, and new safety technologies. In the next century, for example, all commercial jets will use satellites to navigate and communicate their positions to air-traffic controllers on the ground; a tremendous advantage over ground-based navigation aids and radar that lose "sight" of planes once they fly beyond the horizon.

Additionally, aviation industry organizations around the world are working together to reduce the accident rate. For example, in the U.S., airlines, labor unions, and manufacturers have joined the FAA in a Commercial Aviation Safety Team (CAST) that is working to achieve an 80 percent reduction in the rate of fatal commercial accidents of the next 10 years (Boeing, 1999).

So where will these safety improvements come from? Mechanical equipment in aircraft, such as engines, hydraulic systems, and electrical systems have many years of development and refinement in their history. Manufacturing processes used for building aircraft use the latest materials and technologies and produce precise and consistent components, which allow for aircraft to be assembled according to very high tolerances and exceptional quality. There are continually small improvements in these areas yet, as will be discussed below, this will probably not be the source for a large reduction in the accident rate.

Inside the aircraft, the instruments, avionics and electronics have also evolved to show significant improvements over the past several decades. "Glass" cockpits with integrated displays, Flight Management Systems (FMSs) and autopilots are highly reliable and allow the pilot to fly the aircraft more precisely, economically and with improved safety. Each year, there are a number of new technologies introduced into the cockpit with promises of improved safety. However, with these new devices, experts are concerned about the changing role of the human from an active pilot to a systems monitor. This has been a source of considerable debate for many years (Wiener and Curry, 1980). Many experts agree that adding more technology and automation to the cockpit may actually *decrease* aviation safety in the future by removing the human, with its unique qualities, from a decision-making role in the cockpit.

If the safety improvements are not likely to come from the aircraft hardware, then how can the accident rate be reduced?

At the risk of repeating a commonly quoted statistic, flight crew error has been identified as a primary cause in approximately 70% of all hull loss accidents of commercial jet aircraft (Boeing, 1998). This figure appears to be even higher

(82%) in a study conducted by the Flight Safety Foundation which analyzed 287 approach and landing accidents between 1980 and 1996 (Flight Safety, 1999).

Given these statistics and the desire to reduce the accident rate, it appears obvious that perhaps the most rational area to look for improvements in aviation safety is in the nature of human errors in the cockpit.

Cockpit Task Management: A Topic Worthy of Study?

Cockpit Task Management

The primary focus of the present research is Cockpit Task Management (CTM). Formally, CTM is the initiation, monitoring, prioritization, execution, and termination of multiple, concurrent tasks by flight crews (Funk, 1991). In other words, it is a theory of how humans manage and perform multiple, concurrent functions while in the operational context of an aircraft flight deck.

CTM is practiced every day by pilots and almost without exception, pilots perform it satisfactorily and fly many thousands of hours without incidents or accidents. However CTM on the flight deck is a legitimate safety concern for commercial transport aircraft. Several studies presented below have shown that CTM errors contribute significantly to aircraft incidents and accidents.

CTM on the flight deck is not new; pilots have always done it. Rather, recent advances in cognitive psychology, engineering psychology and associated methods have been able to better identify and investigate it. CTM appears to be a large part of the of the crew's role on the flight deck, yet understanding of it is in its infancy and design processes have yet to adequately address it. As the existing aircraft fleet is upgraded with new avionics technologies, and new aircraft designs are developed, the complexity of the human-machine interface continues to increase. It is of paramount importance that human cognitive limitations are considered in these designs, and we attempt to eliminate the accidents that have been attributed, in part, to CTM errors.

CTM Terms

As with most research fields, a specific vernacular is used to discuss the theories, models and concepts of CTM. A set of terms and definitions are presented below to provide a basis for further discussion of CTM. Funk (1991) formalized these terms in his primary work in this area, which have been subsequently used in much of the CTM research to date.

Behaviors are a collection of system input, state and output values over time. A system exhibits a behavior if observed values of input, state, and output values match those of the behavior. For instance, by increasing the throttle settings (input), the aircraft accelerates to rotation speed (state), and begins to fly (output). The aircraft exhibits the flying behavior by matching the inputs, state and outputs of the flying behavior.

A *goal* for a system, such as an aircraft, is defined by a set of desired behaviors. If one of the behaviors is realized, then the goal is achieved. Otherwise, the goal is not achieved. For a commercial air transport mission, the primary goal might be to transport people large distances to a destination quickly, comfortably and economically while maximizing the safety of the passengers and crew. From this primary goal, many *subgoals* can be identified and spawned as a set of behaviors consistent with those of the goal, but of limited scope with respect to the primary goal. For example, in a flight mission, a subgoal may to climb to an altitude established by air traffic control (ATC), say 15,000 ft. This subgoal is consistent with the primary goal, but identifies more specific behaviors that may lead to the realization of the subgoal and eventually, the primary goal.

A *task* is a process that is completed to cause a system to achieve a goal. The processing of a task to achieve a goal requires resources, which may be other systems or subsystems. For example, to prepare an aircraft for departure, the resources from the human system may be necessary. In general, tasks require resources to achieve a goal.

Resources may take the form of equipment such as autopilots, radios, displays and controls. Human resources include the people on the flight deck, such as the captain, first office or flight engineer. Human resources can be decomposed into subsystems, such as physical and mental resources, and mental resources can be further decomposed into subsystems such as working memory, and attention (Wickens, 1992).

At any time, tasks can be in any one of five possible states (See Figure 2-1.). Initially, a task is *latent*, meaning that it is present or potential, but not currently evident. When the task's initial event is imminent, the task moves to the *pending* state, where it follows the initial event into the *active* state. A task moves into *active in progress*, when resources are allocated to the task. From the *active in progress* state, the task can return to the *active* state (if resources are deallocated) or it can move to the *terminated* state (if the task's goal is achieved or is unachievable). Additionally, the task can move directly from the *active* to the *terminated* state if the task's goal becomes achieved during a period when no resources are currently allocated to the task.

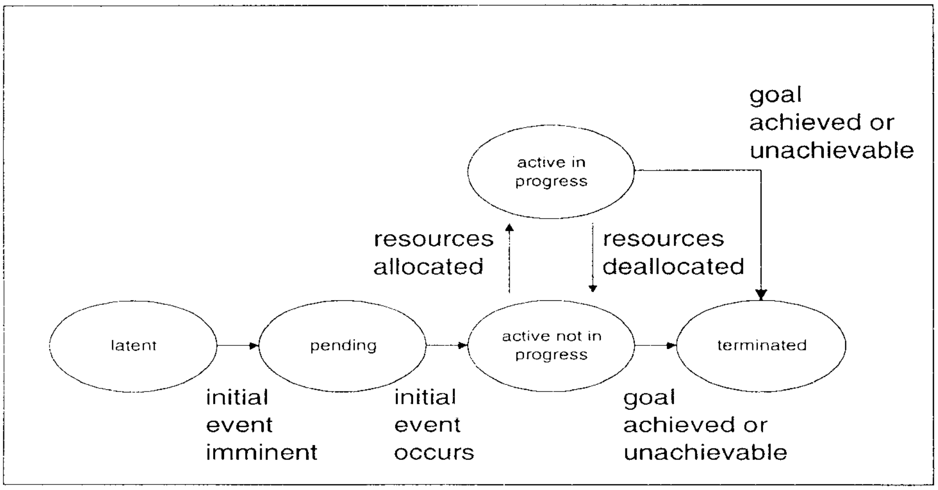


Figure 2.1 Task States (Adapted from Funk, 1991).

The *level of specification* is the extent to which subgoals are identified. In the analysis of flight deck tasks, the level of specification can be decomposed into many simple, specific tasks. For instance, a task as simple as advancing the throttles can be broken down into individual motor tasks specifying very detailed movements. This is usually not desired in the study of tasks on the flight deck, and a more realistic and manageable level of specificity is adopted. Thus, the task "prepare aircraft for departure" may be an appropriate level of detail in much of CTM research.

Funk (1991) identified the notion of an *agenda,* which facilitates the study of CTM. An agenda is a hierarchical structure of tasks to be completed during a flight. As each task becomes relevant to the flight, it will move through the states identified in Figure 2.1. Each task in the agenda has its own goal, and if multiple tasks become active simultaneously, they are called concurrent tasks.

As multiple, concurrent tasks enter the active state it is possible for the resource requirements to overwhelm available resources. This is particularly relevant when more human resources are required than are currently available. In other words, task performance is limited by resource availability. The inconsistency is obvious when multiple tasks require physical resources like hands or eyes, but not so apparent are the instances where conflicting demands are placed on cognitive resources. *Task conflict* occurs when task resource requirements exceed resource availability.

Funk's later work on the concept of an agenda led him to the concept of *agenda management* (Funk, et al., 1997; Funk and Braune, 1999). Definitions and terminologies were changed slightly to incorporate the idea of an *actor.* An actor is an entity that is capable of goal-directed activity. An actor can be a human, but can also be flight deck automation equipment such as autopilots, flight management systems, or automated warning and alerting systems. Additionally, he stated that actors can have conflicting goals, and these conflicts may lead to conflicting actions. Although this was a valuable concept, the present research continues to use the term Cockpit Task Management (CTM) to maintain consistency with previous work.

CTM Errors

The underlying causes of aircraft accidents usually fall into the three broad categories of mechanical factors, weather factors, and pilot error. CTM errors, of course, fall under the latter category. A classic example of the failure of pilots to perform proper CTM comes from the Eastern Airlines L-1011 accident near Miami (NTSB, 1973). In this instance, the crew failed to attend to the primary task of flying the airplane while attempting to diagnose a landing gear status lamp failure. This crew misallocated resources to tasks that, in hindsight, were obviously of low priority compared to the task of keeping the aircraft in the air. The result of this CTM error: 99 fatalities. The Eastern Airline accident is but a single example of a CTM error that may have contributed to an aircraft accident. Chou (1991) and Madhavan (1993) provide tens of CTM error examples that are presented and analyzed in depth.

Chou (1991) developed a CTM error taxonomy to aid in the analysis of accidents like the Miami accident. The purpose of this taxonomy was to provide a tool to analyze incident and accident data to determine, in a consistent manner, if CTM errors were present. The CTM error taxonomy presents three error categories: Task initiation errors, task prioritization errors and task termination errors. Within each of these categories, specific errors can be classified according to their nature (see Table 2.1). This taxonomy was then subsequently applied in several studies of CTM errors in accidents, incidents and a part-task simulator study.

Error Categories	Possible Classifications
Task initiation	Early
	Late
	Incorrect
	Lacking
Task prioritization	Incorrect
Task termination	Early
	Late
	Incorrect
	Lacking

Table 2.1 CTM Error Taxonomy (Adapted from Chou, et al., 1996).

CTM Errors in Aircraft Accidents

Using the preliminary theory of CTM and the CTM error taxonomy, Chou (1991) performed a study of aircraft accidents. His hypothesis was that CTM errors contribute, at least in part, to a significant number of aircraft accidents.

He reviewed 324 National Transportation Safety Board (NTSB) accident reports. A first pass eliminated accidents that clearly did not involve CTM errors. Of the 76 remaining accidents, he reinterpreted the NTSB findings into the CTM error taxonomy. It is important to specify that he did not perform his own accident investigation, but used the findings of the NTSB as data to be analyzed using the proposed CTM error taxonomy.

His findings were that in 76 of the 324 accidents (23%), CTM errors were present. While these are significant findings, Chou is careful to point out that the accidents cannot be attributed to CTM errors alone, but that CTM errors may have contributed to the accidents.

CTM Errors in Aircraft Incidents

In a similar study, Madhavan (1993) performed a CTM error study of Aviation Safety Reporting System (ASRS) incident reports. An incident, in the aviation domain, signifies a regulation violation or an unsafe flight condition, but does not involve a catastrophic event like an accident. Madhavan's hypothesis was that CTM errors were significantly present in aircraft incidents.

He selected 470 ASRS reports which included in-flight engine emergencies, controlled flight towards terrain, and terminal phases of flight (final approach). The ASRS reports, which contain a narrative of the incident, where used as that data to drive the analysis using the CTM error taxonomy.

The results found that of the 420 incident reports analyzed, 231 (49%) contained CTM errors. In fact, a total of 349 CTM errors were found in the 231 incidents. Madhavan is careful to point out that his method relied heavily on the reporter's own admission of misallocation of attention and that the CTM error may not have been the primary cause of the incident.

CTM Errors in a Part-task Simulator

In a different approach to investigation of CTM errors from the previous studies, Chou (1991) performed a part-task simulator study, with the objective of eliciting CTM errors in a laboratory environment, rather than reviewing reports of errors which occured in an operational environment.

His method was to have 24 subjects fly a single-pilot, part-task simulator consisting of three networked computers simulating a generic, two-engine commercial transport aircraft. The varied conditions of the flight scenarios were the workload requirements, the number of concurrent tasks and the complexity of the flight path. The performance metrics for the study were the average time to respond to equipment faults, the root-mean-square of flight path error, task prioritization score and the number of tasks that were initiated late.

His findings indicated that CTM errors increase with an increase in workload and a combined effect with flight path complexity and the number of concurrent tasks.

CTM Errors and Level of Automation

As was mentioned in the introduction, a controversial issue within the human factors community is the idea that aircraft automation increases safety. Wilson (1998) performed an ASRS study to examine the effect of the level of automation on the rate of task prioritization errors on the flightdeck.

Her method was to randomly select 420 ASRS reports. 210 reports were selected from aircraft classified by the ASRS as advanced technology (high automation) and 210 from conventional technology (low automation) aircraft. The other requirements for selection of reports were that the aircraft were large commercial jets with two pilots flight decks and the incident occurred between 1988 – 1993.

She reviewed the report narratives for task prioritization errors and found that the rate of CTM errors was higher in the aircraft with the advanced technology automation. However, she was careful to acknowledge that the rate of CTM errors in high automation aircraft showed signs of slowing, which may indicate that pilots are becoming more familiar and proficient with automation.

Summary

The investigation of CTM under Funk is approaching almost a decade in duration. First, identification of CTM as a cognitive process was conceptualized and formalized. Next, an error taxonomy of CTM was developed and applied in several studies of accidents, incidents and a part-task simulator. These studies all contribute supporting evidence to one critical point: CTM is significant to system safety and system effectiveness.

The next logical research question, then, is what can be done about CTM errors? Do the solutions lie in better pilot selection or training? Perhaps a better pilot-vehicle interface design would reduce CTM errors. How about a pilot aid to facilitate CTM?

While all of these have had some research activity, only the last, facilitation of CTM, has attempted to specifically address improvement in pilot task management performance. This topic will be discussed in the next section.

CTM Facilitation

The fundamental concept behind CTM facilitation is to assist the pilot in the task management function. While to date, it has not addressed better training or equipment design, surely those are areas ripe with opportunity. Rather, CTM facilitation has been directed at assisting the pilot with CTM functions such as:

1. Maintaining a current model of aircraft state and current flight deck tasks
2. Monitoring task state and status
3. Computing task priority
4. Reminding the pilots of all tasks that should be in progress
5. Suggesting that the pilots attend to tasks that do not show satisfactory progress

Concurrent to the research efforts in identifying and characterizing CTM were efforts directed at aiding pilots with the management of tasks on the flight deck. The present section presents several efforts directed at enhancing and facilitating CTM though the use of pilot aids.

While there are tens or hundreds of examples of experimental pilot aids, this review focuses on those specifically directed at management of tasks. At the highest level, there are two endpoints to a spectrum of task management pilot aids: procedural scripts and cognitive models of the pilot, which perform tasks in differing levels of automation (Funk and Lind, 1992). The limitation of the purely procedural script approach is that it lacks the power and especially the flexibility needed for assisting the pilot in a true operational environment. On the other hand, the pilot model-based approach may be unrealistic, as cognitive models are still so limited (Anonymous, as cited in Funk and Lind, 1992).

Task Support System

The research performed by Funk and Lind (1992) was to approach task management at an intermediate level of complexity between procedural scripts and pilot cognitive models. The Task Support System (TSS) was developed as part of a prototype avionics system designed to improve pilot situational awareness and reduce manual and mental workload through advanced software and information display methodologies. The TSS was task-oriented, providing greater flexibility than rigid checklist-oriented systems. Yet it contained no explicit pilot model, instead relying on the structure of the pilot's task/subtask hierarchy to guide its operation.

The TSS was essentially an advanced, integrated avionics configuration that consisted of a collection of two types of specialized, active software units called agents. Each system in the pilot's environment was represented by a system agent, and communicated with other agents as to its status. A task agent assumed responsibility for the completion of each specific task. Task agents helped the pilot perform tasks by configuring displays, monitoring his actions, providing procedural assistance, making recommendations, and completing some actions automatically.

The experimental evaluation of the TSS in a simulated environment resulted in improved performance on some tasks, moderately reduced workload and a preference of the TSS system over a baseline avionics configuration.

Cockpit Task Management System

Following the successful demonstration of the TSS, Funk and Kim (1995) extended the theory behind CTM to create the Cockpit Task Management System (CTMS), which included goal representation. They defined a goal, in the context of the flight deck, as a desired aircraft or system state, and a task as a process to achieve a goal.

The CTMS system consisted of a separate display area, which was dedicated to helping the pilot initiate, monitor, prioritize and terminate tasks. From a software perspective, the CTMS employed a similar approach to TSS, using system and task agents.

Following the development of the CTMS, a simulator study was performed to evaluate its effectiveness. Use of the CTMS over the baseline configuration resulted in a reduction in misprioritization errors, response time to critical events, unsatisfactory aircraft control duration and the number of tasks pilots failed to complete.

AgendaManager

The AgendaManager (Funk, et al., 1997; Funk and Braune, 1999) was a significant, evolutionary iteration in this line of research. They realized that human pilots were no longer the only actors in the cockpit, because automation such as autopilots, thrust management computers, and flight management systems played a more active role in the control of advanced technology aircraft. Like human actors, these machine actors are goal-directed systems that use complex data or knowledge bases to determine their behaviors.

To incorporate the concept of machine actors, they suggested that a goal was achieved through a function rather than a task. Therefore, the management of activities in the modern flight deck must address both human and machine functions. Additionally, they identified goal conflicts between human and machine actors, which was another dimension of CTM that must be addressed.

Finally, pilot intentions in the AgendaManager were captured using a speech recognition system to interpret the pilot's acknowledgement of ATC clearances.

The evaluation of the AgendaManager was performed again in a simulated environment. The baseline configuration consisted of an Engine Indicating and Crew Alerting System (EICAS), a system found on many commercial aircraft. The results indicated that the AgendaManager performed equally well on functions it had in common with EICAS, but additionally improved pilot performance in the identification of goal conflicts and improved prioritization.

Summary

The present section has presented an evolutionary perspective on the facilitation of CTM. What began as a special configuration of military avionics has evolved into a stand-alone pilot aiding system with the objective of helping pilots perform task management functions on the flight deck.

One of the criticisms to such a pilot aid is that, on the flight deck, where pilot workload and attention allocation is critical, it is effectively one more display (task) to which the pilot must attend. In other words, pilots already have periods of extremely high workload conditions. During these periods, when CTM is so critical, a pilot aid that assists in task management functions may in fact demand attention from the pilot and detract him from performing those mission critical tasks.

Further, the pilot aids described above are essentially nothing more than intelligent memory aids. Since there is still much to learn about the nature of CTM, one might question if this is the best approach to realize significant gains in task management performance. Only a better understanding of the task management process will ultimately answer this question. Fortunately, there have been significant efforts toward a better understanding of CTM. In the next section, works directed towards better CTM theories are presented.

Theories of CTM

A theory is a collection of statements about a subject domain (Funk, 1983). The statement of a theory may be posed in a natural language, a purely formal language, such as a computer programming language, or a mathematical language, such as differential equations or the language of probability theory.

The theories of CTM that have emerged over the past decade have all taken the form of natural language theories. While these works have significantly added to the knowledge of CTM, there is still much not understood about the nature of CTM, especially some of the internal processes such as goal generation and task prioritization. The following sections provide a summary of the theories of CTM.

The Normative Theory of CTM

The following procedure and explanation comprise a normative theory that was developed to help define and characterize CTM (Funk, 1991). CTM is described as a procedure that is executed by the flight crews to manage the flight deck tasks as follows (See also Figure 2-2):

1. Create an initial agenda.
2. Until mission goal is achieved or determined to be unachievable:
   a. Assess current situation.
   b. Activate tasks whose initial events have occurred.
   c. Assess status of active tasks.
   d. Terminate tasks with achieved or unachievable goals.
   e. Assess task resource requirements.
   f. Prioritize active tasks.
   g. Allocate resources to tasks in order of priority.
   1. Initiate newly activated high-priority tasks
   2. Interrupt low-priority tasks (if necessary).
   3. Resume interrupted tasks (when possible).
   h. Update agenda.

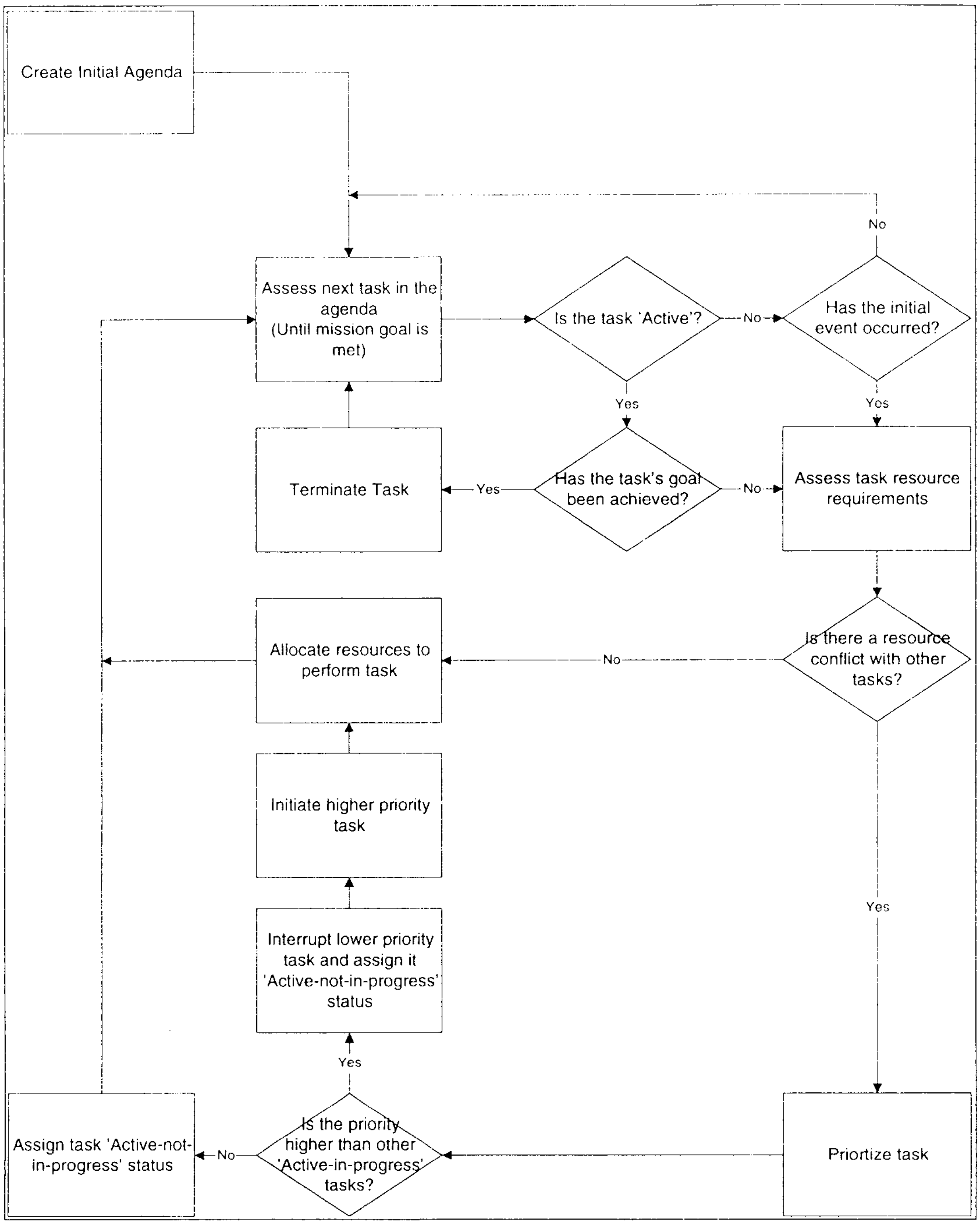


Figure 2.2 The Normative Theory of CTM (Adapted from Funk, 1991).

Given a hierarchy of goals to accomplish during a mission, the first step for the flight crew is to create the initial agenda. This agenda consists of a task to achieve each goal and an initial event must be defined for each goal-task pair.

Once the agenda has been established, the process of agenda management begins and continues until the mission goal is achieved or has been determined unachievable. In the case of the mission being determined unachievable, the process should end only after the aircraft and its subsystems reach some safe state.

The flight crew must assess the current situation. The states of all relevant aircraft systems and subsystems must be considered to determine if significant events have occurred.

When initial events occur, the flight crew must activate tasks that are contingent upon those events. This means that these tasks enter the *active* state and should become *active in progress* as soon as resources are available.

The flight crew must assess the status of active tasks to determine if satisfactory progress is being made toward achieving the tasks' goals. Not only must the current status of each task be assessed, but if the task's goal is not yet achieved, the status of the task must be projected into the future to determine the likelihood that the goal will be achieved. A task's status may be declared satisfactory if its goal is achieved or is likely to be achieved, marginal if achievement of its goal is uncertain, or unsatisfactory if the goal is violated or is unlikely to be achieved without corrective action.

Based on this assessment, the flight crew should terminate tasks with achieved or unachievable goals. The task goals that become irrelevant due to changing circumstances should also be terminated. Termination removes tasks from competition for resources.

For the remaining active tasks, the flight crew should assess task resource requirements to determine what resources are required to complete them. A newly activated task might be started with minimal resources, but a task of marginal or unsatisfactory status might require additional resources to achieve its goal.

The flight crew should prioritize the active tasks. Factors that might influence task priority include the following:

1. The importance and urgency of the task's goal.
2. The importance and urgency of other active tasks' goals.

3. The current and projected status of the task.
4. The current and projected statuses of other active tasks.

Prioritization can be defined as a pairwise comparison of tasks based on these factors and others that result in an ordering of active tasks.

As a result of the previous steps, the flight crew must then allocate resources to tasks in order of priority. This is an assignment of resources to tasks, with preference given to high-priority tasks, so that the tasks may be executed. The flight crew should initiate newly activated high-priority tasks to make them active in progress. They should interrupt low-priority tasks that are active in progress when high-priority tasks requiring the same resources become active. When the high-priority tasks finish and resources become available again, the flight crew should resume interrupted tasks, returning them to the active in progress state. These steps result in a set of tasks in the process of execution.

This process causes changes in the set of *pending* and *active* tasks and changes in task status and priority. The flight crew should update the agenda to reflect these changes and repeat the process.

Strategic and Tactical Task Management Theory

Rogers (1996) presents a similar theory of CTM, which he calls, simply Task Management (TM). He modifies and expands on Funk's normative theory and proposes a preliminary set of discrete flight deck CTM processes based on the review of previous CTM analyses. Each process is given equal weighting and it is assumed that there is a logical sequence, that is, each process depends on completion of the processes preceding it. These processes are, in order of occurrence:

1. <u>Assess situation</u>. The operational context and goals must be assessed in order to identify the set of tasks that need to be performed. The cockpit environment is dynamic and must continually be reassessed as the flight proceeds. In order to know what tasks need to be performed, the pilot must be aware of the phase of flight, aircraft position, aircraft attitude and speed, aircraft and systems states,

environmental conditions, unusual and other significant events, and short and long term goals. Further, he must be able to project this situation knowledge into the future, making predictions about the course of events.

2. Identify tasks. The tasks required to achieve the goals under the current and anticipated circumstances of the particular flight must be identified. Also, as a precursor to scheduling tasks, task characteristics such as time required to complete, deadline, difficulty or complexity, resources required, and sequence interdependencies should be identified.
3. Prioritize tasks. Tasks must be prioritized in terms of urgency. This means the estimates of task deadlines must be compared to one another to determine which tasks are more urgent. Tasks must also be prioritized in terms of *criticality*, that is, how necessary are they to mission safety or success. These relative prioritizations, along with the task characteristics identified above, help in making scheduling decisions.
4. Assess resources. The availability and capability of task resources, including automation, other flight deck personnel, company resources, and the pilot himself, must be determined so that assignments of tasks to those resources can be made appropriately. This involves determining the status and predicted status of each task resource and the ability of the resource to perform part or all of the various tasks that have to be performed. It also includes predicting the pilot's own workload to ensure that tasks assigned do not exceed his limitations.
5. Allocate resources. Human and automation resources must be assigned to perform tasks. This may be a straightforward assignment, as to an autopilot or autothrottle, or it may require negotiation and discussion, as in deciding the division of duties between the crew members on the flight deck if this situation is not specified by procedures or regulations. The allocation process is ongoing; resources may need to be reassigned as conditions and goals change. Backup allocations should be considered, and if resources assigned to tasks are not completely reliable, they must be monitored.

6. Schedule tasks. This element involves setting an order in which the identified tasks should be performed. It also includes the determination of when tasks need to be started, delayed, temporarily stopped, or resumed. It depends not only on completion times, deadlines, priorities, resources, interdependencies, and the overall context but also, in the case of performance by humans (pilots), *momentum* and *continuity*. That is, other things being equal, humans perform better if they can continue working on a task once they have started rather than switching back and forth between tasks, causing discontinuity of thought and action.
7. Perform tasks. This is not considered part of task management. It is included to explicitly distinguish between CTM and task performance. For example, if a call to ATC must be performed, identifying that as a task, prioritizing it, scheduling it, allocating it, etc., constitute task management, but the actual call to ATC is a communication task, not a task management activity.
8. Monitor tasks. Task performance should be monitored relative to the schedule to assure that tasks are started on time, completed on time, and are progressing as expected. Bottlenecks and resource limitations should be identified. If the tasks are not progressing towards completion as expected, then the pilot should consider ways to hurry, delay, or modify task performance in order to meet the schedule. The schedule, the overall situation, or the tasks to be performed may need to be re-evaluated.
9. Manage interruptions. In real-time environments such as commercial flight, interruptions will occur as tasks are being performed. If an interruption is processed, then attention to the ongoing task may be, at least momentarily, suspended. Often the interruption, such as a call from ATC, can signal the requirement to perform a new task, such as reporting position, or changing heading. These interruptions must be managed – the pilot must determine whether to stop the current task to process the interruption, and whether to immediately go back to the current task or to perform a new task if one is associated with the interruption. Further, the pilot must remember at what stage

the first task was stopped so that it can be efficiently resumed, and if the interruption changes overall goals or tasks, the need to continue, terminate or modify ongoing tasks must be assessed.

In addition to the refined theory of normative CTM presented above, Rogers draws three conclusions that appear to be very useful and relevant to identifying the nature of CTM:

1. Strategic and Tactical CTM. There is a very pronounced dichotomy in CTM: strategic CTM and tactical CTM. Strategic CTM is characterized by pre-planning activities, building a mental model, monitoring, contingency planning, filling gaps with continuous and pre-planned items, and performing tasks early to avoid real and potential workload bottlenecks later. These properties were used to describe CTM activities when the flight is proceeding normally and there is little or no time pressure. However, tactical CTM is characterized by dividing tasks (between crew members), using a well-learned, well-rehearsed mental list of discrete items to be performed, doing time-critical, high priority items, operating in "real time," hurrying the pace of tasks, and deferring or dropping tasks. Rogers used these properties to describe CTM activities when there was an emergency or time-pressured situation.
2. CTM is time-driven. The overriding explicit CTM process is scheduling or ordering tasks. The ordering is primarily related to the task's urgency. Tactical CTM is immediate event-driven and strategic CTM is workload-management driven.
3. Categorization of tasks. Tasks are divided into discrete real time tasks, discrete pre-planned tasks, and continuous or repetitive tasks. Discrete tasks are ordered along a priority or time dimension and continuous tasks are interleaved with discrete tasks but not explicitly ordered.

Rogers' work identifies and emphasizes two very important aspects of CTM. First, although Funk's normative theory implicitly gives equal weighting to all CTM processes, Rogers suggests it was the scheduling and ordering of tasks that was the dominant process. Second, the prioritization of tasks was dependent upon the characteristics of the task context. In other words, prioritization in a tactical phase of flight differs from prioritization in a strategic phase.

Personal Workload Management Strategy vs. Monitoring Strategy

Schutte and Trujillo (1996) performed a study where pilots flew a simulator in a primarily tactical CTM mode, where several critical system faults resulted in the need for the pilots to alter the flight plan and land at an alternate location.

They propose that CTM contains two distinct activities: personal workload management and monitoring of the current situation. The monitoring activity comprises the 'assess current situation' and 'assess progress and status of active tasks' of Funk's (1991) normative theory.

Each of these two activities itself can have one of four differing strategies depending on the individual characteristics of a pilot:

1. Aviate-Navigate-Communicate-Manage Systems (ANCS). The conceptual basis of the ANCS task hierarchy is that the preceding task category takes priority over subsequent category. In other words, aviate tasks always have a higher priority than the navigate tasks, which have a higher priority than the communicate tasks, and so on. This is a general prioritization scheme common in the research environment and very well known to pilots. However, it is not difficult to conceptualize situations in which this prioritization scheme breaks down and the tasks take on a priority inconsistent with the ANCS hierarchy. In a strict ANCS prioritization approach, task prioritization occurs with little regard for the context of the situation.
2. Perceived Severity. Subjects place the highest priority on what they perceive to be the most threatening problem.
3. Procedure Based. Subjects migrate towards tasks for which there are well-defined procedures. These range from systems procedures to Federal Aviation Regulations (FARs).
4. Event/Interrupt (E/I) Driven. Subjects' attention is given to a particular task based on an event or an interruption. They will typically continue pursuing that

task until the task is completed, the subject can do no more on the task or until another event or interruption disrupts the task.

The results of the simulator study suggests the pilots use, to some extent, each of these four strategies. However, the performance of the pilots was not equivalent. The authors identified the strategies that resulted in the most effective pilot performance (fewest errors and fastest response times). For the ***personal workload management*** activity, they found that the ***Perceived severity*** strategy resulted in the best pilot performance. For the ***Monitoring*** activity, the ***ANCS*** strategy proved most effective.

Their interpretation of their findings is also very interesting. First, they suggest that CTM is largely dependent on individual differences between flight crews and personal style. Second, the activity of CTM appears to play a significant role in how the flight crew deals with a non-normal situation. In the study, different strategies resulted in different outcomes to the flight scenario. Third, interruptions play a significant part in the CTM of pilots, many of which are due to communication requests from ATC. They conclude that explicit training for normative CTM strategies should be incorporated into flight crew training.

Summary

The current effort has been a summary of past research efforts directed towards CTM. It has covered the definition of a CTM language and the development of error taxonomies used to identify and classify task management-related errors. Several studies examined various reports and found that CTM errors were present in incidents, accidents and a part task simulator study. Efforts were made towards the reduction of CTM errors through CTM facilitation, where pilot aids are used to display and integrate status information from multiple sources. These agent-based aids showed promising results in helping pilots better manage multiple tasks. Other researchers used varying methods to further develop and refine CTM theory, giving new insights into how pilots prioritize tasks. In general, the one conclusion that can be drawn from the existing CTM research is this: CTM is significant to system safety and system effectiveness.

However, it is still evident that the theories are still somewhat vague and many questions about CTM errors continue to go unanswered. There is still much to be accomplished in the area of CTM. The approach taken in this area to date has been from a very operational or ecologically valid perspective. At a very fundamental level, task management is essentially the control of attentional focus and the proper allocation of attention (and other resources) to the tasks on the flight deck. One possible opportunity for further developments in the theory of CTM lies in a better understanding of how the pilot's attention is controlled. Does the pilot consciously perform attentional control, or does the task environment determine where attention is focused? In other words, is attentional focus internally or externally controlled? In the next chapter, CTM is approached from a more fundamental perspective with the intention of working towards a better understanding of the task management process.

CHAPTER 3:
COCKPIT TASK MANAGEMENT: TOWARDS A BETTER UNDERSTANDING

A Human Performance Approach

The Engineering (or Systems) Approach

The existing research to date has approached Cockpit Task Management (CTM) from a systems-based perspective. In other words, it has identified and discussed the inputs, outputs and states of the task management process, but has done so without looking deeply into the process itself. While this approach has made significant progress in the characterization of CTM, there may exist opportunities to discover a deeper understanding of the task management process.

The Human Performance Approach

The present chapter takes an alternative approach: The examination of CTM from a human performance perspective. CTM was investigated according to human behavioral dimensions that appeared to be closely related to the task management process. The source of much of the following discussion comes from a review of research that was performed in the applied and cognitive psychology domains. While systems-based and engineering research often criticizes psychological experiments for the use of abstract, simple tasks or experiments that lack ecological validity, the very specific nature of this type of research may provide new, fresh insights into the nature of CTM. It is hypothesized that the exploration of the human performance characteristics of task management may lead to better research in the more ecologically valid environment of the engineering research approach to CTM.

The Context of CTM

The CTM Continuum: Internal vs. External behaviors

In the complex, multiple task environment of the flight deck, CTM can be conceptualized to lie on a continuum of internal and external behaviors. Figure 3.1 identifies 8 research concepts related to CTM. The items to the right of center have been investigated using an engineering approach directly related to CTM, while the items to the left of center are the focus of the current chapter.

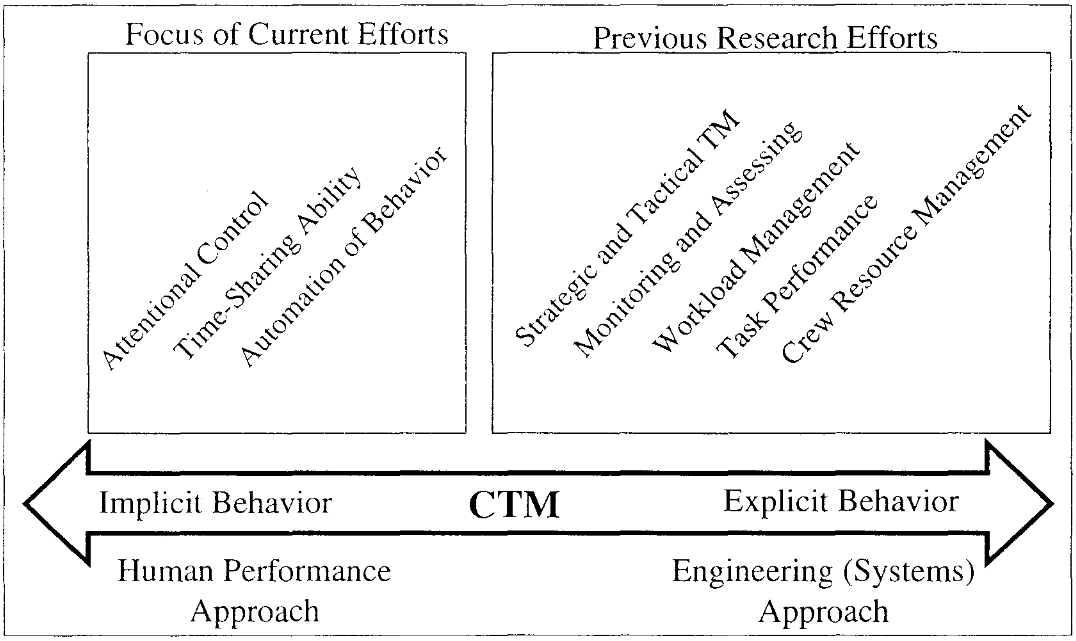


Figure 3.1 The Cockpit Task Management Continuum.

While the external behaviors are readily accessible through direct performance measurement, the internal behaviors present a significant methodological problem, as it is very difficult to measure and quantify such activities. The existing CTM literature has focused on these external characteristics, but has not yet explored the internal characteristics. While there is some discussion of these internal behaviors from other research areas, the present effort appears to be the first attempt to apply such concepts to CTM.

These internal behaviors occur within the mind. They include processes, such as dynamic attentional control, that are concerned with the moment-by-moment adjustment of behavioral goal priorities, with the planning and sequencing of behavior, and with the maintenance and/or shifting of a selective task set. While these processes provide some of the most challenging and interesting research questions, they have attracted relatively little research over the last 25 years, even in the areas of experimental and cognitive psychology (Allport, 1992).

Automation of Behavior

Automation of Task Performance

Continued practice in a multiple task environment will eventually lead to improved task performance. There are at least two possible reasons for the improvement. First, it may be that humans are able to develop very exacting control over the allocation of their limited resources to perform the tasks. In other words, the allocation of resources can be performed at near optimal levels, where each effort contributes to attaining the current goals. This executive control of attention is the topic of a subsequent section.

However, it has been well established that continued practice on a single task will improve performance (Wickens, 1992). Therefore, in multiple task environments, continued practice on each of the tasks may lead to better overall performance of all the tasks. This improvement in task performance with practice is called the automatization of a task, and is a fundamental dimension of human performance.

Schneider and Shiffrin (1977) suggested this classification of task performance into a controlled-automatic processing continuum. *Controlled processing* (CP) is characterized as a slow, generally serial, effortful, capacity-limited processing mode that must be used to deal with novel or inconsistent information. *Automatic processing* (AP), on the other hand, is a fast, parallel, fairly effortless process that is not limited by short-term memory capacity, is not under direct subject control, and is responsible for the high performance of well-developed skilled behaviors.

There are four stages in the transformation of tasks from controlled to automatic mode (Schneider and Shiffrin, 1977):

1. Pure controlled processing. Memory load negatively affects performance.
2. Flattening of the memory load curve. A result of practice, both controlled and automatic processing occur.
3. Nearly automatic processing. Automatic processing, but attention is allocated to assist automatic processing.
4. Pure automatic processing. No attention is allocated to the automated task, so concurrent attention-demanding tasks will not degrade automated task performance.

AP typically develops when an individual processes stimuli consistently over many trials. Some of the critical characteristics of automatic processing are the ability of the individual to shift from serial to parallel processing, a reduction in workload, a reduction in processing control, and a dramatic reduction in the ability to learn during automatic processing (Damos, 1991).

As a single task is learned and practiced, it moves from CP mode towards AP mode, and its demand on information processing resources is decreased. The task can be performed with less effort and with less attention paid to the task. The same can be said for the multiple task environment. As multiple tasks are practiced, they become more automated, and require less attention and performance improves. This form of improvement does not actually result from acquisition of an attentional control or time-sharing skill, but from a reduced resource demand of each individual task (Wickens, 1992).

Relevance to CTM

The previous section documents improved task performance on the execution of tasks due to the effects of practice and automatization of the tasks. While the literature has not come to a final conclusion if this is the fundamental cause of improved multiple task performance, there is strong evidence that automatization of tasks does improve multiple task performance. However, is the ultimate objective to train the pilot so extensively that all tasks are performed in AP mode? Is it possible? Is this desirable? Does it really free resources so additional tasks can be performed?

In their study of controlled and automatic processes, Schneider and Fisk (1982) reported that under time-sharing conditions, task elements that were automated after prolonged training still captured attention, although controlled attention was not required to assure performance. Dedicated training efforts were needed to teach subjects to relax and release attention. This is an indication subjects were unable to voluntarily control the allocation of their attentional resources, and significant automatization did not lead to improved multiple task performance.

Additionally, the natures of some tasks on the flight desk are not good candidates for automatization. Norman (1988) discusses capture errors, in which a frequently performed behavior suddenly takes over instead of the behavior intended. For example, a primary task on the flight desk is communication with ATC. Much of this communication involves the interpretation of verbal clearances, which establish the goals for subsequent tasks. While these clearances are often very consistent from flight to flight, there is no guarantee and the clearances do change significantly from flight to flight. In an incident report (NASA, 1992), a pilot was given a clearance to descend to 3500'. However, this clearance was inconsistent with his past experiences of the situation as an altitude of 3000' was usually designated for the particular flight. Therefore, even though the ATC clearance of 3500' was clearly audible and perceived by the pilot, a capture error was committed and he interpreted the clearance to be 3000'. While the air traffic controller in this situation was operating within federal regulations, the automatization of the pilot's behavior of this simple communicate task resulted in a situation that could have easily resulted in a very unsafe condition (e.g., a midair collision). For some tasks on the flightdeck, it is surely desirable that they be performed in a CP mode, for the potential improvements in task performance due to AP are far outweighed by the potential consequences of a capture error in such situations.

In high workload situations, pilots do need to have tasks, to a large extent, in AP mode. According to Chou's (1991) findings, as workload increases, CTM errors increase. Therefore, if some tasks can be performed in AP mode, it may release some cognitive resources, allowing the pilot to manage multiple tasks. Current training techniques, where pilots practice procedures through many repetitions, supports this concept. Pilots, in general, are very well trained on normal procedures, such as aircraft control and normal checklists. However, one of the human's very unique and desirable characteristics is to deal with novel situations, where behavior will occur in a CP mode. Therefore, it is not even desirable to have a pilot perform entirely in AP mode. Additionally, AP opens the door for capture errors and in reality, some tasks just don't lend themselves to AP mode (e.g., ATC communications). Therefore, total automatization of behavior is not the answer.

Voluntary Control of Attention

Evidence of Control

Can humans voluntarily control where attention and other resources are allocated? As one reads this paragraph, what if a fire alarm was to sound? Would the reader switch attention from the page to the alarm? The author would suggest that the reader would, at least momentarily, switch attention from the page to the aural alarm. With training and practice, would the reader be able to ignore the ongoing alarm and continue to attend to the paragraph being read? The literature suggests the answer is yes (Gopher, 1992).

Although attention control has rarely been a direct topic of research, several series of studies support the claim that humans can actively control attention. For example, Posner, Snyder, and Davidson (1980) suggest humans are able to adopt a selective set of stimuli to which to attend. Data that documents the successful division of attention comes primarily from experiments with the dual-task paradigm (Gopher and Donchin, 1986). One line of studies has documented consistent individual differences in attention-switching capabilities as a factor distinguishing between good and bad performers of complex tasks (Gopher, 1982; Gopher and Kahneman, 1971; North and Gopher, 1976). This evidence supports the ability of subjects to adopt and successfully apply graded levels of attention allocated to a task.

In the operational flight deck environment, a pilot would benefit most if he could fully attend and respond to all elements of all tasks at all times. However, such full attention is not possible. In fact, though we may be able to apparently perform several tasks at once, we can devote thoughtful, conscious attention to only one at a time (Adams and Pew, 1990; Adams, et al., 1991). Therefore, some compromises and priorities must be established along with attention-allocation strategies. Setting priorities in a task environment is a common behavior, but the question is how efficient are humans in establishing allocation strategies, especially in a complex, multiple task environment such as the flight deck?

With few exceptions (e.g., Logan, 1985; Allport, 1992), strategic control of attention in operational environments has never been a major topic of research in experimental psychology. Gopher (1992) suggests that a *strategy*, in this context, is defined as a vector of differential weights or attention biases assigned to tasks. It influences the performer's behaviors with respect to the requirements of the task. A strategy represents the solution implemented by the performer to achieve performance objectives, within the boundaries of his processing and response limitations. In other words, selection of an attention allocation strategy is an evaluation of a vector of factors, with the prioritization of multiple tasks being the result. It is not clear, however, if this evaluation is an explicit, conscious cognitive function. On the contrary, it may be a function that is performed subconsciously by the pilot.

But what is the underlying nature of such strategies? One popular view attributes all such control processes to a unitary central executive or supervisory attention system (SAS) (Baddeley, 1986; Norman and Shallice 1986). Unfortunately, according to at least one scientist (Allport, 1992) the concept of a central executive has yet to be elaborated in a way that avoids the homunculus problem.

Allport (1992) suggests that there is little evidence of such a unitary (and simple) theory of attention. One fault with such a theory is the assumption that attentional functions were all of one type. Rather, he suggests the idea that attentional functions are of a very many different kinds, serving a great range of different computational purposes. There can be no simple theory of attention, any more than there can be a simple theory of cognition. In other words, the nature of attention allocation in a multiple task environment is complex, and depends upon such factors as the nature of the task and the training, experience and abilities of the performer. However, identification of these factors has not yet been accomplished.

Evidence of Failure of Control

In addition to positive evidence of attentional control abilities, there is evidence of problems, failures, and limitations.

Gopher and Donchin (1986) found a degradation of primary task performance when a secondary task was introduced, despite clear instruction to protect the performance of the primary task. Traditionally, this decrement in primary task performance has been attributed to capacity overload. However, Gopher (1992) suggests that it may be more a lack of attentional control on the part of the subject. Subjects may not be able to correctly allocate only spare capacity to the secondary task, thus protecting the primary task. Gopher suggests the subjects do not have adequate knowledge about the attention costs of performing each of the tasks.

While researchers have been able to document graded levels of performance on tasks, this was only accomplished with the use of augmented feedback (Navon and Gopher, 1979; Gopher, Bricker, and Navon, 1982). In other words, subjects could perform tasks at several different levels of performance, but they required special, on-line, augmented feedback displaying the consequences of emphasis changes on their performance to do so successfully. Without such feedback, subjects were unable to perform multilevel adjustments (Spitz 1988).

Gopher (1982) and Spitz (1988) found that in many dual-task situations, subjects had as much difficulty lowering their standard of performance for the task for which priority was reduced as they had in improving performance for the task on which priority was increased. It appears that subjects have difficulties lowering performance and reducing efforts on one task. They cannot easily release resources for the performance of another high-priority task, while still maintaining minimal control over the low-priority task.

Therefore, even though there is strong evidence that humans are able to voluntarily control attention, in all three types of failures of control presented above, the nature of difficulty appear to stem from subjects' lack of ability to efficiently control the allocation of their attentional resources.

Relevance to CTM

To date, the CTM theory has suggested that task management is the explicit, serial process in Figure 3-2 (Funk, 1991). Rather, CTM may be an exercise in the control of attention and proper allocation of resources to tasks. Further, the CTM errors that have been identified (Chou, et al., 1996) may be a result of the lack of attentional control and the inability to efficiently allocate resources properly.

The human performance literature suggests two opportunities for the improvement of attention control. First, Gopher (1992) has found extensive evidence that the effect of "variable priority" training not only improves performance of individual tasks, but more importantly, it improves the efficiency with which subjects allocate resources. In other words, the technique develops executive control to improve the efficiency with which attention is allocated to competing tasks.

Secondly, past research (Navon and Gopher, 1979; Gopher, Bricker, and Navon, 1982) suggests that augmented system feedback has a significant effect on the subject's ability to change attention allocation strategies. This is supportive evidence of past CTM facilitation efforts by Funk and his colleagues (Chou, et al., 1996). While continued pursuit in this area could bring about integrative flight deck systems that could better aid the pilot in the proper allocation of attention to tasks, the fact remains that there still exists limited knowledge of the CTM process. The first step is to better understand how CTM functions, and more specifically, how task prioritization is accomplished.

Time-Sharing Ability

Human time-sharing skill is knowing when to sample what from all available information sources, when to make which response, and how to integrate better the flow of information in multiple, concurrent tasks (Wickens, 1992). It is suggested that humans incorporate the performance improving effects of the automatization of tasks and the attentional control abilities presented in the previous sections to better perform multiple tasks in an operational environment.

Switching attention from one task to another is an aspect of voluntary control that has been widely employed in the study of attentional limitations (Gopher, 1992). The main interest in most studies has not been in the properties and control of switching, but rather in contrasting serial and parallel models of the human processing system. Several studies have documented consistent individual differences in attention-switching capabilities as a factor distinguishing between good and bad performance of complex tasks (e.g., Braune, 1986; Gopher, 1982).

When observing the expert perform multiple, complex tasks, such as flying an aircraft, the novice is often amazed at the ease with which the expert can effectively time-share a number of separate activities. However, as the novice gains experience, he too is able to perform multiple, concurrent tasks at an acceptable level of performance. But is the improvement in performance due to the development of a specific time-sharing ability, or merely just more practice with each individual task?

There is evidence of a general time-sharing ability (Damos, and Wickens, 1980; Gopher, 1992). It was shown that training this ability with one set of tasks was generalizable to other tasks. However, what was concluded was that very efficient time-sharing performance of the expert results not only from the true skill of time-sharing, but also from the development more automated behavior on the individual tasks. This conclusion, then, adds another dimension to the management of multiple, concurrent tasks.

Summary

The purpose of the preceding sections was to explore alternative approaches to studying CTM and establish future directions. In this approach, CTM is considered from the perspective of human performance related to the automatization of task performance, the voluntary control of attention and human time-sharing ability. It was not the intention to fully explore each of these concepts in their own contexts, but rather to provide a general perspective to discuss the nature of CTM.

The CTM theories discussed in Chapter 2 fail to incorporate the human performance characteristics of multiple task performance discussed above. Specifically, the characteristics of Funk's normative theory (Figure 2.2) that ***assesses task resource requirements***, ***determines if a resource conflict exists***, and ***prioritizes tasks***, do not elaborate on how human abilities are able perform such functions.

With respect to ***assessing task resource requirements***, the automaticity of the task must be considered. Some tasks, such as primary aircraft control and sequential tasks, such as normal checklists, can be performed largely in AP mode. However, there are some tasks on the flight deck that are not good candidates for automatization (i.e., interpretation of ATC clearances). Further, the existence of a ***resource conflict*** may depend upon the automaticity of a particular task to a particular pilot. Pilots with many thousands of hours in a particular model of aircraft may be able to perform common tasks in AP mode while also communicating with ATC. However, other pilots may not have developed such efficient automatic behaviors on the same common tasks, thus they are not able to equal the expert performance of the well-practiced pilot.

Existing theories of CTM treat the ***prioritization of tasks*** as a simple queue of tasks to be completed. However, in the context of the flight deck, tasks are performed in a complex time-sharing mode, where attentional focus engages a task for a short period, switches to another task, then may again return to the original task. It is in this area that human abilities to voluntarily control attention and effectively time share between tasks becomes important for a deeper understanding of the management of multiple tasks. In the following section, a primary research question is extracted from the approach described above, which will be the focus of the subsequent chapters.

Research Question

One of the topics of multiple task performance that continually arises in both the CTM and human performance literature is that of the prioritization of tasks. An initial assumption can be made that tasks are performed in the order of priority assigned to them by the person performing the tasks. However, due to the very dynamic nature of tasks on the flight deck, this assumption may not always hold true (i.e., by the time the first task is complete, the situation has changed and new priorities exist), but for purposes of this research, it is considered a satisfactory approximation. Then the question can be phrased: What determines the order in which tasks are performed?

Gopher (1992) postulates that attention strategies can be defined as vectors of factors that combine performance objectives for elements of complex tasks, in the service of a higher-level goal to establish driving forces of attention allocation. This suggestion may provide a framework with which to describe the process of task prioritization. However, Gopher admits that even if this view is accepted, there is still a lack of knowledge about the factors and mechanisms that represent strategies and about the forces that drive them.

Logan (1985) suggest two factors, cue validity and resource requirements, that affect task prioritization, but he asks what other factors determine how humans allocate attentional strategies to multiple tasks.

Adams and Pew (1990) suggest a more specific approach to prioritization in the context of multiple task management:

> Though we may be able to do several things at once, we can devote thoughtful, conscious attention to only one at a time. The implications are, first, that the management of multiple cognitively complex tasks must consist essentially in working on one while queuing some number of others. Second, the queue of to-be-attended tasks cannot be worked through any simple first-in first-out heuristic. Instead, the tasks in the queue must be prioritized with deference to both the temporal requirements on their execution and their overall importance to the management of the situation as a whole. Within actual systems, moreover, the nominal set of tasks in the queue as well as their relative priorities change dynamically as a function of events and of changes in the status of the subsystems involved. Grappling with these issues is forcing us to recognize a variety of questions that are in dire need of research.
>
> Yet the queue cannot be productively conceived as a list: Like the tokens in explicit focus, those in the queue must correspond to pointers to knowledge structures in memory – structures that detail the procedural and declarative

> knowledge about each task and that must be accessed in its prioritization, reprioritization, scheduling, and execution.
>
> Because, more than anything else, it may be maintenance and prioritization of this queue that must determine the pilot's capacity to respond appropriately to the individual demands of the scenario, it is worth examining its cognitive requirements more closely. For purposes of discussion, these requirements can be divided into two (nonindependent) subsets: (1) How does the pilot prioritize the pending tasks? And (2) What are the factors that determine when she or he will shift attention to any particular task in the queue?

The question, then, is quite clear:

What are the factors that affect task prioritization?

The references cited above all suggest that there are factors that affect task prioritization, but for the most part, fail to predict what these factors might be.

The CTM literature has posed several predications on the factors, however there exists little empirical evidence to support the presence of these factors in a complex environment such as the flight deck. Table 3.1 is a compilation of 13 factors that may affect task prioritization (Funk, et al., 1998; Pashler, 1998; Schutte and Trujillo, 1996; Rogers, 1996).

The literature suggests that identification of the factors that affect task prioritization is a topic lacking in research efforts. However, from the citations above, several individuals agree the investigation of these factors is worth pursuing. Since CTM is concerned primarily with human performance in the context of the commercial aircraft flight deck, this is a logical next step in the investigation of CTM. Therefore, the present CTM research effort is directed towards investigating these prioritization factors. Stated very simply, the question posed in the present research is:

What are the factors that affect task prioritization in the operational context of the flight deck?

1	**Advance knowledge of upcoming tasks** - tasks are performed early to reduce workload during very busy periods
2	**Discriminability of task-related stimuli** - the tasks with salient stimuli are given high priority
3	**Differences in level of effort required to process task-related stimuli** - an evaluation of the effort required to process information is performed, and prioritization is affected by the result of the evaluation
4	**Temporal proximity of task-related stimuli** - tasks related to recently sampled stimuli are given high priority
5	**Task importance: aviate > navigate > communication > manage systems** - tasks are performed strictly in accordance with their classification in the ANCS taxonomy, without regard to current context
6	**Perceived urgency of task** - the time to complete the task is compared to the time remaining until the task must be complete and the task with the least difference is given high priority
7	**Task difficulty** - the difficulty of performing the task is evaluated and prioritization is affected by the result of the evaluation
8	**Task proficiency** - the level of automaticity of a task affects the prioritization
9	**Task recency** - tasks that were performed recently are given high priority
10	**Task momentum** - the tendency to continue to perform the current task affects task priority
11	**Task proximity to completion** - the continuation of a task that is nearly complete is given high priority
12	**Amount of effort already invested in tasks** - tasks that have already received considerable efforts are given high priority
13	**Perceived task status** - the status of a task is evaluated for its status (satisfactory/unsatisfactory) and the result affects prioritization

Table 3.1 Prediction of Factors that May Affect Task Prioritization.

CHAPTER 4:
INITIAL IDENTIFICATION OF FACTORS THAT AFFECT TASK PRIORITIZATION ON THE FLIGHT DECK

Introduction

Over the past decade, cockpit task management (CTM) has been isolated as a cognitive function that is intuitively well understood by pilots and almost always performed satisfactorily. However, there are documented accounts where tasks were not managed properly, resulting in an incident or accident (Chou et al., 1996). A very vivid example of improper CTM can be drawn from the 1972 Eastern Airlines accident in Miami, Florida, where the failure of a gear-down lamp ultimately engrossed the full attention of 3 pilots who failed to respond to an autopilot disengagement. The aircraft descended into the ground, killing 99 people on board (NTSB, 1973). Other CTM error examples can be found in Chou (1991) and Madhavan (1993).

Task prioritization, in the context of the flight deck, is defined as the proper allocation of attentional resources to tasks in order to achieve subgoals which support the overall mission goal. In other words, proper task prioritization ensures the pilot is "doing what he should be doing." A CTM prioritization error occurs when attentional resources are allocated to a task with a lower priority at the expense of another, higher priority task. Funk (1991) identified several categories of CTM errors. One of those error types, improper task prioritization, has been shown to be significantly present in both aircraft accidents and incidents (Chou, et al. 1996).

Of the existing work that has been done in the area of task management, none have addressed task prioritization exclusively. Stated very simply, this part of the study attempted to identify which factors pilots use to determine task priority, and ultimately, what task they will allocate their attention towards. For a comprehensive background of CTM and related topics, see Chapter 2.

In this experiment, pilots flew arrival procedures in a part-task simulator. Two knowledge elicitation techniques were used to probe the subjects for factors that influenced their attentional prioritization scheme while performing multiple, concurrent flight deck tasks.

Knowledge Elicitation Techniques

There are two primary challenges with studying task prioritization or attention allocation strategies. First, it is very difficult to determine what pilots are attending to at any particular instant. It is accepted that the location of eye focus is often a good indication of where one's attention is focused at a particular time. This is especially true in an environment such as the flight deck, where much of the task-related information is obtained visually. However, it is also very evident that this is not always the case. A pilot can be looking at a display, but truly be thinking about something totally unrelated to the display. This situation may occur quite often, and it is extremely difficult to determine from the external perspective of an experimenter.

Secondly, if we were able to satisfactorily determine to what the pilot was attending, the next challenge is to determine why. In other words, how does the task prioritization process work? Is it an internally-driven process, where the pilot uses all past experiences as a knowledge base to implicitly prioritize tasks, or is it a process driven by the environment, where a pilot merely reacts to events as they occur on the flight deck?

Task prioritization and attention allocation may very well be an internal, implicit process that is not directly accessible through any known measurement equipment or techniques (Adams, et al., 1991). The approach in this part of the study was to use knowledge elicitation techniques to verbally probe pilots as to what factors influence their task prioritization while flying.

The literature documents tens of knowledge elicitation techniques, each having advantages and disadvantages depending on the particular task environment (Salter, 1988; Cooke, 1994). Often, the recommendations are to use multiple techniques in order to emphasize each technique's strengths and minimize its weaknesses. In general, each technique varies in its requirements. Some techniques are best implemented in a natural environment, while others are best used in a laboratory setting.

Another concern with knowledge elicitation techniques is the intrusiveness of the method: how much the technique disturbs normal task performance. The more intrusive a technique is, the more difficult it will be to use in an actual operational setting and the more it may disturb the very nature of the task being performed. This may result in the acquisition of knowledge that is not entirely representative of true task performance.

A fundamental characteristic of elicitation techniques is that of ecological validity: the measure of how much a task is like the actual task of interest. Actual task performance is clearly the most ecologically valid environment, and the data generated in that setting will be a very good sample of true task performance. However, thorough investigation of true task performance is not always possible, especially in an environment such as the piloting of an aircraft, where Federal Aviation Administration (FAA) regulations are but the first hurdle to data collection on the flight deck. Additionally, the complexity of the operational setting, the very aspect that gives task performance its ecological validity, often makes it difficult to isolate the relevant behaviors and knowledge. This tradeoff is inherent: the more ecologically valid the task setting, the more complex; the more complex, the more both data and noise are generated and collected; the more data and noise, the more difficult to separate them, and to focus on the questions of interest. On the other hand, in a simplified simulation environment, with a well-defined task and goal structure, performance data can be carefully and accurately collected. However, this same isolation may so transform the task that the knowledge used in this environment may significantly differ from that used in the true operational environment.

In the present study, two elicitation techniques were used: retrospective comment analysis (referred to here as the "retrospective" technique) and interruption analysis (the "intrusive" technique). These techniques were chosen for their strengths, their practicality of use and their compatibility with the equipment available for the present research.

In the retrospective technique, task performance is recorded as it occurs naturally, then reviewed for analysis with the subject. This is usually performed with the use of videotaping equipment, allowing for the subject to be placed back into the context of the task environment as much as possible.

One of the advantages of the retrospective technique is the ecologically valid data that can be collected, as tasks can be performed with little or no intrusion. However, the shortcomings of this technique include the possibly limited ability of the subject to remember and interpret behaviors after the situation has passed. The retrospective technique is best for explicit knowledge elicitation, however in certain circumstances, this technique can allow the subject to observe the application of his implicit knowledge and perhaps verbalize this implicit knowledge.

In this experimental study, the retrospective interview was employed with the aid of a videotaping system. The pilot performed an entire flight scenario while being videotaped. The videotape was a picture-in-a-picture configuration, where upon review, the pilot and experimenter could review both the instruments of the simulator and the body movements of the pilot. At predetermined situations in the scenario, the videotape was stopped, and the pilot probed for task prioritization information (see the cognitive interview section below for a description of the probing technique).

The intrusive technique involves observing the subject performing the actual task, and then interrupting the subject during actual task performance and probing about aspects of what has just occurred. While this method can be applied in a highly ecologically valid task environment, the task must lend itself to being interruptible. Thus in aviation research, for obvious reasons, such a method could never be applied in actual flight conditions, but is limited to flight simulators. Additionally, it is important to recognize that once task performance has been interrupted, the task environment has changed, so this method may not accurately obtain data of the behaviors of interest. Often, because of the intrusive characteristic of this method, it is used to focus on one aspect of task performance at a time.

In the intrusive technique used in this study, the pilot again performed a flight scenario on the simulator. However, at predetermined points in the flight scenario, the simulator was stopped, and the pilot was probed immediately. Following the interview, the flight scenario was again resumed until the next probe.

The justification of selecting these two techniques for this study is three-fold. First, because the current study was an initial investigation of task prioritization, it was in the hypothesis generation phase. Due to the nature of the free dialog during both the retrospective and intrusive interviews, the data tends to be extensive and at a relatively high level of detail suited for hypothesis generation. Second, if the intrusive technique was found to be too disruptive to the task environment, there would still be a significant amount of data collected during the retrospective interviews to be useful. Alternately, if the retrospective technique was found to elicit lower quality data, then the data collected using the intrusive technique could still be useful. Finally, one of the questions posed in the current study was a determination if there was any difference in the data collected using the two techniques, as it is anticipated that follow on studies will be performed using one or both of these techniques.

The Cognitive Interview

As described above, the interviewing opportunities in this experiment were determined by either the intrusive or retrospective elicitation techniques. However, once the probe was initiated, the actual form of the questioning was consistent between the two methods. The cognitive interviewing technique formed the basis of the probe questions during each of the interviews.

Many interviewing techniques are based on the structured interview, where the interviewing method and questioning are presented to each subject in a consistent manner. This is an attempt to minimize extraneous variables in data collection by presenting an environment where the questions and all participant-experimenter interactions are predetermined. Using this technique provides a very systematic approach, with little opportunity for experimenter bias. However, on the other hand, there is little opportunity for the subject to elaborate on internal thoughts and justifications of observed behavior.

Fischer and Geiselman (1992) developed the cognitive interviewing technique. Its initial application was in crime investigation, where investigators were tasked with interviewing eyewitnesses to crimes. They found that traditional interviewing methods had several shortcomings that often hampered criminal investigations. Through extensive development and testing, Fischer and Geiselman established that the cognitive interview is superior to traditional eyewitness interviewing techniques in gathering specific details about a crime. They identify 13 basic concepts that aid in the retrieval of detailed information that is stored in memory, but is not readily accessible. Not all of these concepts are appropriate for this application of the technique, but some were anticipated to be very useful in extracting the information about how the pilot prioritizes tasks in an operational environment. The 13 concepts of the cognitive interview are:

1. Encouraging active information generation on the part of the subject.
2. Active listening on the part of the interviewer.
3. Asking open-ended questions.
4. Pausing after the subject's response before asking follow-up questioning.
5. Not interrupting the subject during information retrieval.
6. Explicitly requesting detailed descriptions of information.
7. Encouraging the subject to concentrate intensely.
8. Encouraging the subject to use imagery.
9. Recreating the original event context.
10. Adopting the subject's perspective
11. Asking subject-compatible questions.
12. Following the sequence of the cognitive interview.

13. Establishing rapport with the subject.

At the core of the cognitive interview are several key concepts. First, the interviewer should strive to recreate the original context of the situation of interest. Second, the subject should be encouraged to form mental images of the situation, and the interviewer can facilitate that effort by carefully worded questions and ample time for the subject to form the images. Finally, the interviewer should help guide the subject through a systematic evaluation of those mental images. Through these concepts, at least in eyewitness interviews, a surpassingly rich and complete recall of information can be achieved.

In order to use the cognitive interview in this experiment, the experimenter extensively studied the cognitive interviewing technique and practiced applying it to subjects before data collection began.

Probe Selection Points

One of the critical aspects of this study was the selection of the probing conditions. One of the hypotheses of prioritization strategies is that the prioritization of tasks is directly related to the task environment. The challenge for the present research is to select points that are not identical conditions, but representative of the task environment.

One approach was to randomly select data collection points. This was not chosen for the following reason. The task environment is very dynamic, and pilots move from being almost idle to quite busy, and vice versa, very quickly. With relatively few data collection points for each pilot, the high probability of probing a pilot during a nearly idle condition is quite high. This study was investigating the tactical or reactionary characteristics of behavior and was not focused on strategic or planning-ahead behaviors, when current task demands were few (see Chapter 2). Therefore, a systematic probing strategy was desired that queried pilots when they had multiple tasks active, yet not identical task conditions.

This study identified three types of events. These events are generally representative of the tactical flying environment of an arrival/approach phase of flight:

1. **Procedure Events** – these are events that occur as part of the mission tasks. For instance, as the pilot intercepts the instrument landing system (ILS) localizer (see Glossary in Appendix 1), the indication needle begins to move. This is a cue for the pilot to begin the turn onto the final approach. It is a standard procedure for pilot to follow: when the instrument commands turning the aircraft on to final approach, the pilot performs the task. These are anticipated events, and the pilot waits for the cue to begin the task, then follows the procedure to complete the task.
2. **ATC Events** – these are the incoming Air Traffic Control (ATC) calls that the pilots must interpret, adjust goal structures and then form and deliver a response. These are often expected events, but the exact time of occurrence and detailed content is not known.
3. **Malfunction Events** – these are unexpected events. They represent some equipment malfunction in the aircraft. These are of a cautionary nature, and can be immediately threatening to the airworthiness of the aircraft. The pilot knows the correct procedure to respond to and fix these malfunctions.

At each of these events, a probe opportunity exists just before and just after the event. Because of the nature of the intrusive interviewing technique, it is not practical to probe both before and after each of these events during a single scenario, as there was insufficient time to resume the simulator flight scenario. Therefore, only one of the opportunities (before OR after) was probed during the each of the scenarios. (For a complete description of the experimental design, see below.)

Prediction of Factors that Affect Prioritization

As mentioned above, the objective of this study was to identify the factors that pilot use to prioritize tasks. A review of the task management literature found no other studies that have specifically addressed this issue, so this appears to be the first study of its kind. While no data collection has been performed on this topic, the literature suggests factors that drive task prioritization (see Table 3.1).

It was anticipated that if this list was presented to pilots and instructions given to classify which of these factors affect their prioritization scheme, the reply would be a blank stare. Therefore, the approach used in this study was to let the pilots verbalize, in their own words, how and why they prioritized tasks in the simulator environment. The elicitation and interviewing techniques described above were used to merely provide an opportunity for the pilot to verbalize prioritization schemes. These interviews were then analyzed after the interviews, and the pilots' responses were categorized into prioritization factors.

Summary

The present study was essentially performed with hypothesis generation as a primary objective. Virtually no data had been collected in an operational environment on how pilots prioritize the multiple, concurrent tasks that are inherent on the flight deck. It was anticipated that through this experiment, an initial indication of the factors that affect task prioritization would be gained.

Method

Participants

The participants for this study were 8 airline pilots, all male, with an average of 7472.5 total flying hours. They had an average of 984.4 hours of single pilot time and 666.9 hours of electronic flight instrument system (EFIS) experience. Their age range was 25 to 44, with an average of 35.6 years. They were recruited on a volunteer basis and were not compensated in any way.

Equipment

The part-task simulator was the NASA Stone-Soup Simulator version 4.1 obtained from NASA-Ames Research Center. The hardware consisted of 2 SGI Indigo2 workstations, running the IRIX 6.2 operating system. The workstations were networked together, with one serving as the experimenter's station and the other displaying the simulator interface for the pilot. The simulator flight control was performed with a B&G Flybox and a mouse connected to the pilot's workstation. Video equipment included a Panasonic 8mm camcorder, Sony PVM-1910 video monitor and Videonics MX-1 video mixer to obtain the picture-in-picture configuration. Video from the pilot's workstation was collected using an SGI Galileo Video board and software for NSTC video output. Audio equipment included a Panasonic WM-F2040 stereo cassette recorder to record pilot interviews.

Experimental Design

Data collection for the experiment consisted of two flight scenarios, designated as Bravo and Sierra (Figure 4.1 and Figure 4.2). These were similar scenarios, yet different enough that pilots could not anticipate ATC instructions for headings, altitudes and airspeeds or timing and type of equipment malfunction events. Subjects were balanced so that half of the subjects ran the Bravo scenario first and half ran the Sierra scenario first.

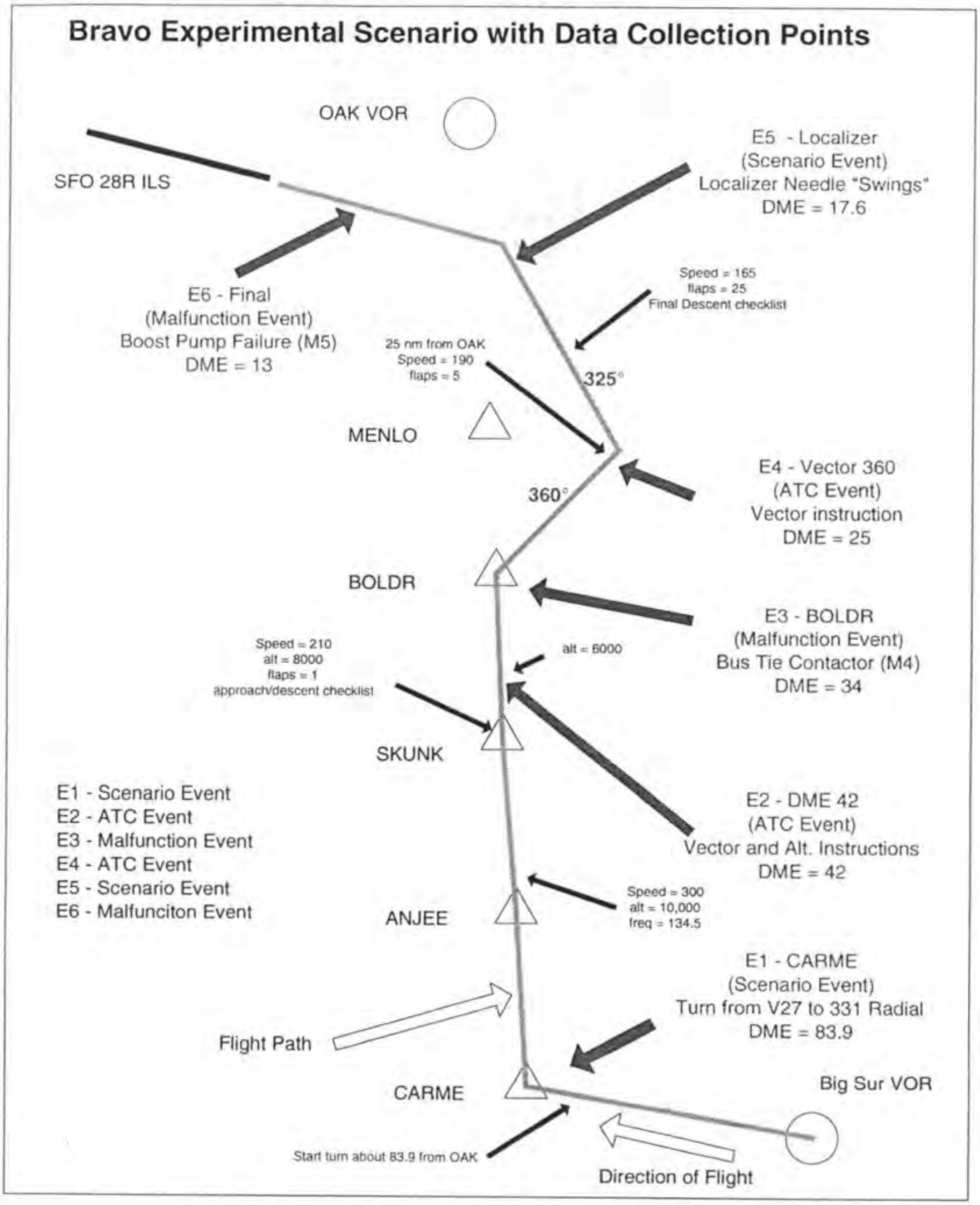


Figure 4.1 The Bravo Scenario.

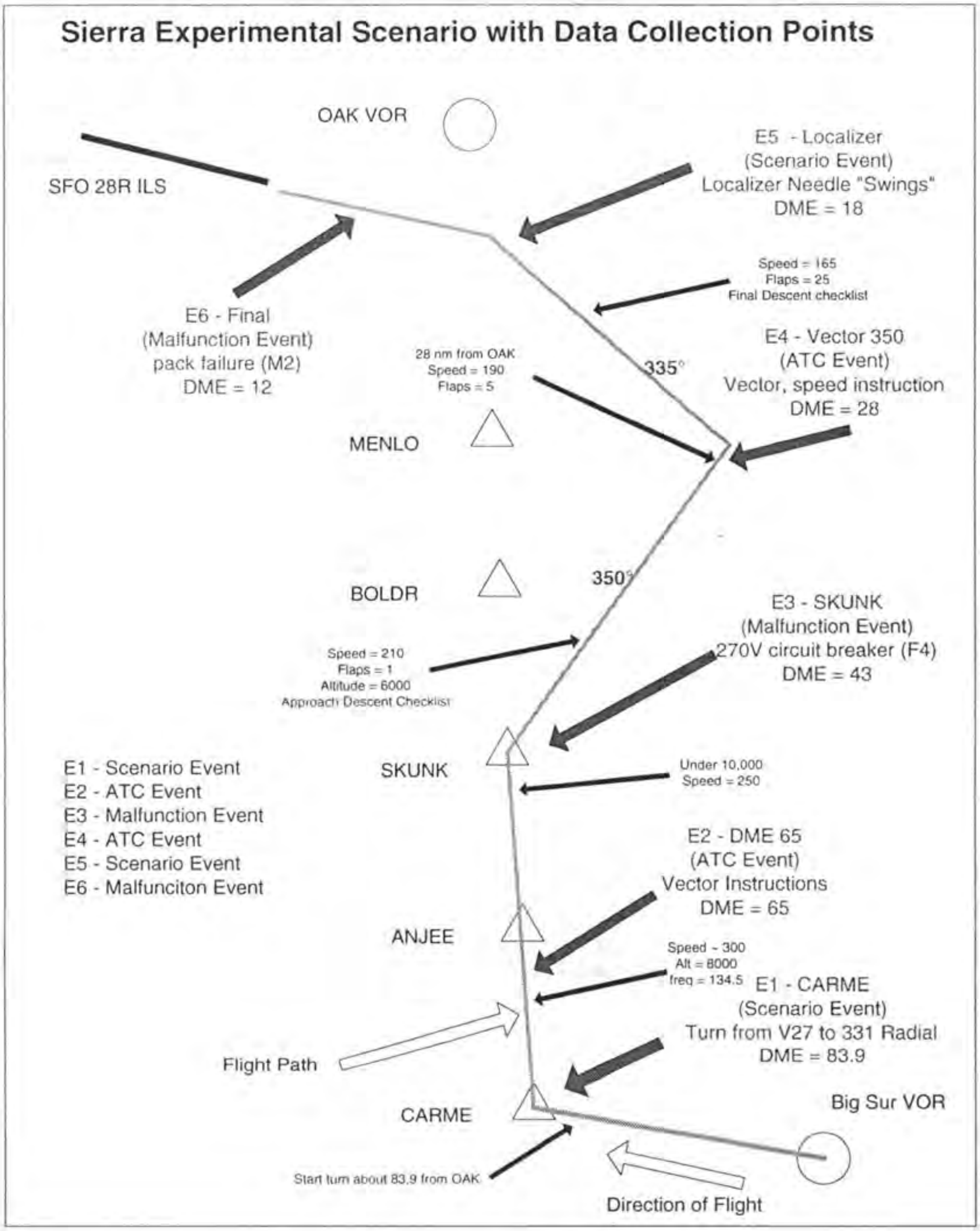


Figure 4.2 The Sierra Scenario.

In each scenario, the elicitation method used was either the retrospective technique or the intrusive technique. If the subject performed the intrusive technique first, then the retrospective technique was used on the second scenario. Subjects were balanced so that half performed the intrusive technique first, while half performed the retrospective technique first.

In each scenario, six events were identified: two procedure events, two ATC events and two malfunction events (see Figures 4-1 and 4-2). Pilots were then probed just before or just after each event. The design was such that if a pilot was probed just before the first event on the first scenario, then he was probed after the first event on the second scenario, and vice versa, thus getting full coverage of the event over two scenarios. This was the case for all six events in each scenario, thus totaling twelve probes over both scenarios.

The experimental design was a full 2 x 2 x 2 factorial design with a full, single replication using 8 subjects. The treatments were: Scenario Order (Bravo/Sierra), Elicitation Technique (Retrospective/Intrusive) and Probe Timing (Before Event/After Event). This was given to the 8 subjects according to Table 4.1.

Subject #	1st Scenario	Retro/Intrusive	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
1	Bravo	Retro	Before	After	Before	After	Before	After
2	Sierra	Retro	Before	After	Before	After	Before	After
3	Bravo	Intrusive	Before	After	Before	After	Before	After
4	Sierra	Intrusive	Before	After	Before	After	Before	After
5	Bravo	Retro	After	Before	After	Before	After	Before
6	Sierra	Retro	After	Before	After	Before	After	Before
7	Bravo	Intrusive	After	Before	After	Before	After	Before
8	Sierra	Intrusive	After	Before	After	Before	After	Before
Subject #	2nd Scenario	Retro/Intrusive	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
1	Sierra	Intrusive	After	Before	After	Before	After	Before
2	Bravo	Intrusive	After	Before	After	Before	After	Before
3	Sierra	Retro	After	Before	After	Before	After	Before
4	Bravo	Retro	After	Before	After	Before	After	Before
5	Sierra	Intrusive	Before	After	Before	After	Before	After
6	Bravo	Intrusive	Before	After	Before	After	Before	After
7	Sierra	Retro	Before	After	Before	After	Before	After
8	Bravo	Retro	Before	After	Before	After	Before	After

Table 4.1 Experimental Design.

Simulator tasks

The tasks performed in the part-task simulator were designed to be consistent with actual flying tasks as much as possible. At the highest level, the mission goal was to fly the simulator the final 100 miles of an arrival into the San Francisco International airport (SFO). Pilots were given the published Big Sur-2 Standard Terminal Arrival Route (STAR) plate and a procedure plate for the San Francisco runway 28-right instrument landing system (SFO 28R ILS).

While the simulator's displays and behavior was similar to a real aircraft, there were significant differences that required explanation to the pilots. For example, tasks such as dialing radio frequencies and altitude dial settings were accomplished using software buttons manipulated by the mouse instead of the physical knobs as in actual aircraft. The purpose of the explanation was to familiarize the pilots with the display layout and manipulation of the simulator's various controls (See Figure 4.3).

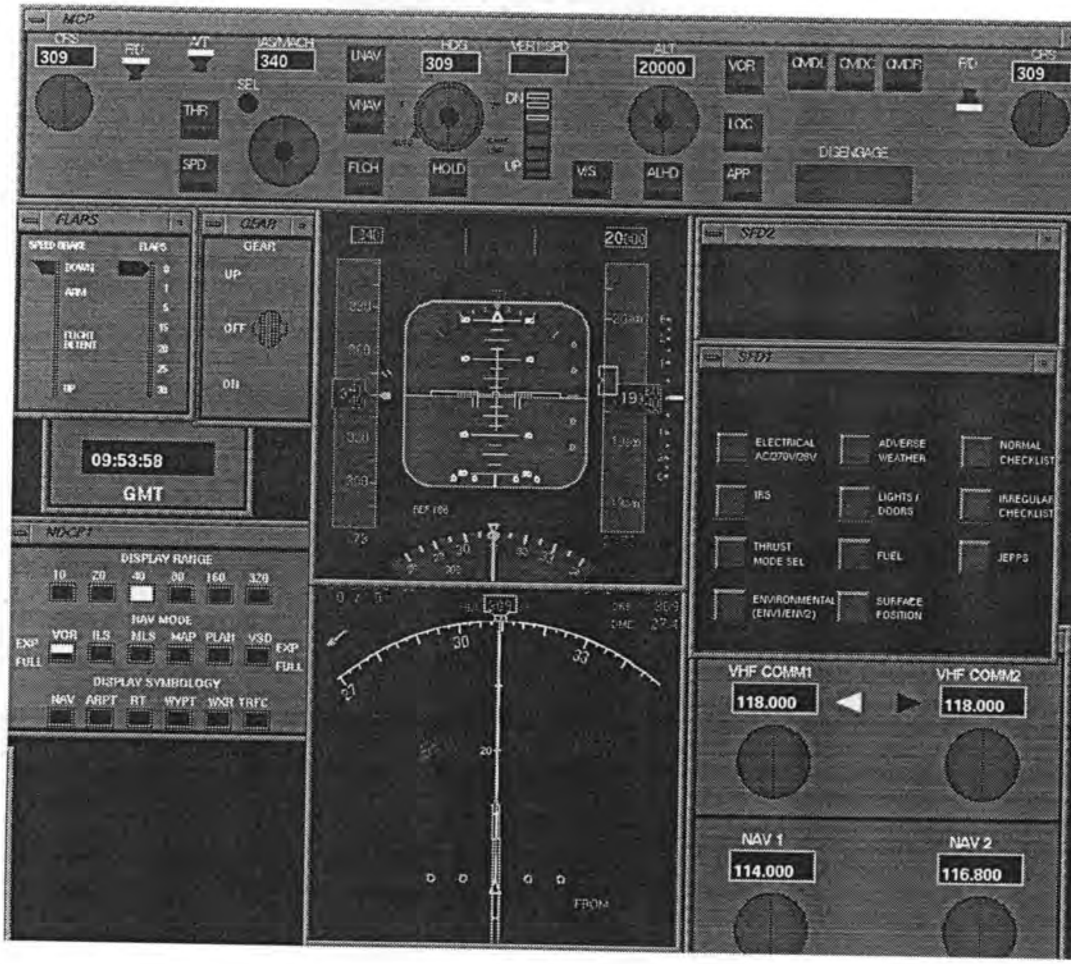


Figure 4.3 Stone Soup Simulator Screen Shot

Primary aircraft control was accomplished by manipulating the joystick for pitch and roll. There were no yaw control devices, such as rudder pedals. No use of automated flight control, such as autopilots, were allowed for this study. However, use of the flight director was required, and was very beneficial in aiding primary aircraft control. The flight director consists of command bars located on the attitude indicator, which direct pilot joystick inputs to accomplish desired heading and pitch for the aircraft. This functionality was used in an attempt to moderate pilot effort in primary control, since joystick input to the simulator was very sensitive.

Navigational equipment was limited to a single very-high-frequency omnirange (VOR) navigational instrument (see Glossary in Appendix 1 for aviation equipment definitions). While this is a very minimal configuration, it was ample for the scenarios and is an accurate partial representation of true navigational tasks. VOR displays and controls consisted of the navigational display, which included a VOR deviation indicator, DME distance from the ground-based VOR, course setting and VOR frequency. The VOR frequency control was located on the navigational radio display, and the course input selector (CRS) was located on the mode control panel.

Communications between the pilot and simulated ATC was performed by direct verbal exchange, as the pilot and experimenter were within approximately 5 feet of each other. Verbal exchanges were restricted to standard radio procedures and there was no free conversation between pilot and experimenter during data collection scenarios. As a small added communications task, the pilot was required to dial in the proper communications radio frequency before an exchange with ATC.

Other system management tasks were performed in the simulator through various controls and displays. For example, equipment malfunctions illuminated the caution indicator and display a message in the Engine Indication and Crew Altering System (EICAS) display area. The equipment malfunctions could then be acknowledged and reset by performing a series of mouse click inputs to the multifunction display/control panel of the simulator.

Pilots were never given clearance to fly the entire STAR, but used the information provided on the STAR to provide reference information regarding navigational waypoints and distances. ATC, which was simulated by the experimenter, provided clearances for the pilots to follow which led them inbound for interception of the ILS navigational aids for final approach.

A task analysis for this study was simplified and refined from the analyses performed by Alter and Regal (1992) and McGuire, et al. (1990). This resulted in the 21 tasks listed in Table 4.2. This is consistent with the standard ANCS taxonomy discussed in Chapter 2.

Aviate Tasks	Navigate Tasks	Communicate Tasks	Manage Systems	General Tasks
Monitor/Control ADI	Review Arrival/Approach Plates	Interpret ATC instructions and clearances	Monitor/Manage aircraft subsystems	Plan ahead
Monitor/Control Heading	Set navigational frequency (VOR/ILS) as required	Record ATC instructions and clearances	Other MCP input	
Monitor/Control Altitude (Pitch)	Maintain awareness of altitude restrictions	Acknowledge receipt of ATC instructions and clearances	Correct system faults	
General Scan of Instruments (no specific instrument)	Monitor DME distance	Transmit requests to ATC	Perform checklists	
Monitor/Control Speed	Monitor HSI Display		Change Comm frequency	
	Set VOR CRS dial			

Table 4.2 Simulator Task Analysis.

Procedure

Pilots arrived for the 2.5-hour experiment and immediately completed an informed consent document (Appendix 2) and pre-trial questionnaire (Appendix 3) to record flight experience, age and to ensure no extenuating circumstances interfered with the trial, such as excessive caffeine or lack of sleep the night before.

Pilots were then given a brief overview of the experiment. They were notified that their flying performance was not being measured in this experiment and that their comments made to the experimenter would be separated from their names and would be kept confidential. The sequence of the experiment consisted of approximately 45 minutes of training on the simulator followed by 2 data-collection scenarios flown on the simulator. Each pilot flew a scenario using the intrusive elicitation technique and a scenario using the retrospective technique. The order of the application of techniques was determined by the experimental design outlined above.

The training consisted of 2 or more flights. The initial flight took a very informal form, with the experimenter introducing each of the displays and controls while directing the pilot to fly certain headings and altitudes. During this time, the pilot was free to ask questions about the simulator, as he became familiar with the location and format of information related to piloting the simulated aircraft. After approximately 15 minutes for the initial flight, the simulator was reset, and another flight was initiated. During the second flight, navigation information was given to the pilot in the form of ATC instructions. However, the pilot was still free to ask questions and, if required, the simulator was paused to explain more about operation of the simulator. During these flights, aircraft configuration checklists and equipment malfunction procedures were covered and practiced several times. After completion of the second training flight, the pilot was asked if he felt he required more training to become comfortable with the simulator. On occasion, a pilot requested an additional run through a particular portion of the training flight, and he was accommodated. Each of these training flights was loosely associated with the Big Sur-2 arrival so the pilot could become familiar with the navigational waypoints and DME distances, but the Bravo or Sierra data collection scenarios were never duplicated.

After training, pilots were given the opportunity for a short break. Next, a general description of the data collection scenario was presented, explaining how each of the interviewing technique was applied (retrospective using a videotape playback, and intrusive, immediately interrupting the scenario). The following instructions were given to the pilot:

> *At certain times, I will stop the simulator (or pause the videotape, depending on which scenario we are performing) and I will ask you several questions. Some of these questions will be straightforward, and others will require you to carefully think about your response. There is no right or wrong answer; I just want you elaborate on your answers as much as possible. If something pops into your mind, don't hesitate to just blurt it out, it may be an important detail.*
>
> *Occasionally, I will ask a question, and I will want you to carefully think about the response before you respond. The purpose of this pause is to let you form a mental image of the circumstances before you begin your response. Please don't hold any thoughts back, I am interested in all the information you can generate.*
>
> *I will often refer to "tasks." What I mean by task is just the jobs that the pilot performs while flying. For example, we consider looking at and thinking about the DME distance on the HSI as the "DME task." However, just looking at the PFD is too general for this study, so we will be more specific. For example, what part of the PFD are you looking at? The attitude indicator, the airspeed or the vertical speed? We would call each of these an individual task.*
>
> *Are there any questions?*

The initial data collection scenario then began. Once again, the order of the Sierra/Bravo scenarios and Intrusive/Retrospective methods were predetermined according to the experimental design described above.

For the retrospective technique, the entire flight scenario was flown uninterrupted and videotaped. During the scenario, the experimenter recorded the precise simulator time that each of the events occurred so that the videotape could be paused upon review with the pilot. Upon completion of the scenario, the pilot was repositioned to view the video monitor and a replay of the just-completed scenario was started. As the videotape playback approached each of the event times, the pilot was alerted that a probe would be initiated very shortly. The 30 seconds of videotape preceding the event was reviewed three times and after the third time, the videotape was paused and a probe was performed.

The probe began in a structured manner, asking specific questions about what tasks the pilot was performing when the videotape was paused. The first part of the probe was to establish the task currently attended, the task that was to be attended to next, and a list of remaining tasks that were currently active in the pilot's memory. Following this identification of the pilot's current task list, a series of questions were posed that probed why the current task had a higher priority than the other tasks listed. It was during this portion of the probe that the techniques of the cognitive interview were employed in an attempt to retrieve as much insightful and detailed information from the pilot as possible as to what factors influenced the prioritization of tasks.

The initial dialog of the probe was presented to the pilots as follows:

What task are you attending to right now?

What task will you attend to next?

What other tasks are you currently performing? I don't mean actually attending to the task right now, but other tasks to which you know you must monitor and respond.

Let's now return to the current task. You said you were attending to the ***(current task)****. I don't want you to respond right away, but first carefully consider your response. Think about all the things that were going through your mind while you were working on the* ***(current task)****.*

Why was it that your were attending to the ***(current task)*** *instead of the* ***(next task)****? Take just a few seconds to think about this, then talk as much as you can about* ***why*** *you were attending to this task. I want as much detail about why as you can generate.*

(PAUSE, as the experimenter is writing notes of the response)
(At this point, the experimenter is trying to listen to the response and determine the factors that are being mentioned.

(The experimenter will now have one or more factors recorded on the data collection sheet.)

You mentioned ***(factor 1)*** *as one of the reasons you were attending to the* ***(current task)****. Tell me more about* ***(factor 1)*** *(Pause). Is this something* *usual for you, or is this a special situation? (Pause) Why? (Pause) Is there anything else you can tell me about* ***(factor 1)****?*

(Repeat this for each task and factor)

As was discussed earlier, the cognitive interview allows for deeper probing on certain items reported by the subject. This concept was employed as often as possible in an attempt to get as much information from the pilot as possible regarding prioritization strategies.

For the scenarios that were performed using the intrusive technique, the probing technique was identical. The difference in the intrusive technique is that upon reaching the events in the scenario, the simulator was stopped and the probe initiated immediately, within several seconds of the pilot actually flying the simulator. All probes were recorded using a cassette recorder for further analysis and review at a later time.

After the pilot had completed the second scenario, he was immediately given a post-test questionnaire (Appendix 4), inquiring about how comfortable the pilot was with flying the scenario and if the training was adequate for testing purposes. Additionally, the pilot was encouraged to discuss his thoughts and feelings about anything related to the experiment. This completed the experiment.

Results

Data Analysis

The cognitive interviews of the pilots resulted in approximately 7 hours of audio tape. Although initial identification of tasks and prioritization factors was performed during the interviews, the experimenter performed a more thorough analysis by reviewing each probe response several times. This post analysis resulted in minor adjustments to the task classification, but significant changes to the classification of prioritization factors.

The process of analyzing the audio tapes for task prioritization factors was non-trivial. The probes were reviewed with the objective of determining all of the prioritization factors that pilots reported. After several iterations, the number of factors was set at 12, as this was the minimum number of factors that captured all factors reported by the pilots.

Next, each probe was reviewed in an attempt to determine how long the probe lasted, how detailed the pilot was during the probe and how specific the pilot was regarding prioritization factors. In subsequent replays, the pilots' responses were then categorized into one of the twelve factors. It should be noted that every attempt was made to classify the pilots' responses according to what was said during the probe, and not what was inferred by the experimenter. In other words, the analysis classified what the pilot actually verbalized and no attempt was made to infer beyond what the pilots said.

Reported Frequency

The analysis described above resulted in the identification of 12 factors that affect prioritization (See Table 4.3). The factors in the table include generalized descriptions of the factors, including common quotes from pilot responses. Recall that the task management literature suggested 13 possible factors. However, this study, in essence, began with a clean slate. The factors identified were solely a result of the analysis and not an attempt to fit the pilot's responses into a pre-determined factor classification.

Table 4.4 presents the factors that affect task prioritization in the order of most reported to least reported. Two factors that clearly emerged were status with a total of 51 instances (30%) reported and procedure with 48 instances (28%) reported. In the middle range of frequently reported factors was verifying information, reported 13 times (8%) and importance, reported 12 times (7%). The remaining factors were reported less frequently (see Figure 4.4).

Factor
Procedure – The appropriate (according to the pilot) task to execute in this situation. An environmental cue prompted this task. In this situation, the task is always performed. "When I arrived at the waypoint, I initiated a turn because it was the appropriate thing to do."
Status - Current task status affected the prioritization of the task. "My altitude was 100' feet low and I was still descending. I had to get my altitude back before I could do anything else."
Rate of change – The rate of change or trend of the task status affected the prioritization of the task. "I was currently turning to a heading of 360, and I knew that if I looked away, I would overshoot my desired heading."
Needed information – The task was the source of needed information. "I was attending to the navigational display because it had the information (DME distance) I needed at the time."
Urgency – There was a time pressure to perform the task. "I would be intercepting the localizer very soon, so I needed to configure the instruments for the ILS."
Importance – The task was more important than the other tasks. "On final approach, tracking the ILS is the most important task."
Verifying information – The task was being performed to crosscheck and verify other task status information. "After leveling the wings (using the ADI), I checked the navigational display to verify I was on the correct heading."
Time/Effort required – The time/effort to perform task was small (or large) which affected prioritization of the task. "I replied to ATC first, because it was quick and easy."
Salience of display – The salience of the display prompted that the task be performed. "The caution lights caught my attention, so I fixed the problems before returning to the checklist."
Consequences - The consequences of not performing the task were great. The task has safety implications if it were not performed. "If I didn't initiate a turn, I would be in violation of ATC instructions and it could be a safety consideration with other aircraft or terrain."
Resist forgetting – The task was performed immediately to resist the tendency to forget the goal. "When ATC gives me an altitude, I immediately input the altitude into the panel so I don't forget the number."
Expectancy – The task was performed with an expectancy of upcoming events. "I was looking for things to do now, so I would have less to do when it got busy."

Table 4.3 Factors that Affect Task Prioritization Reported by Pilots.

	Status	Procedure	Verifying Information	Importance	Consequences	Rate of Change	Time/Effort Required	Salience of Display	Urgency	Needed Information	Resist Forgetting	Expectancy
Frequency	51	48	13	12	10	8	7	6	5	4	3	2
Proportion	0.30	0.28	0.08	0.07	0.06	0.05	0.04	0.04	0.03	0.02	0.02	0.01

Table 4.4 Factors that Affect Task Prioritization – Frequency and Proportion.

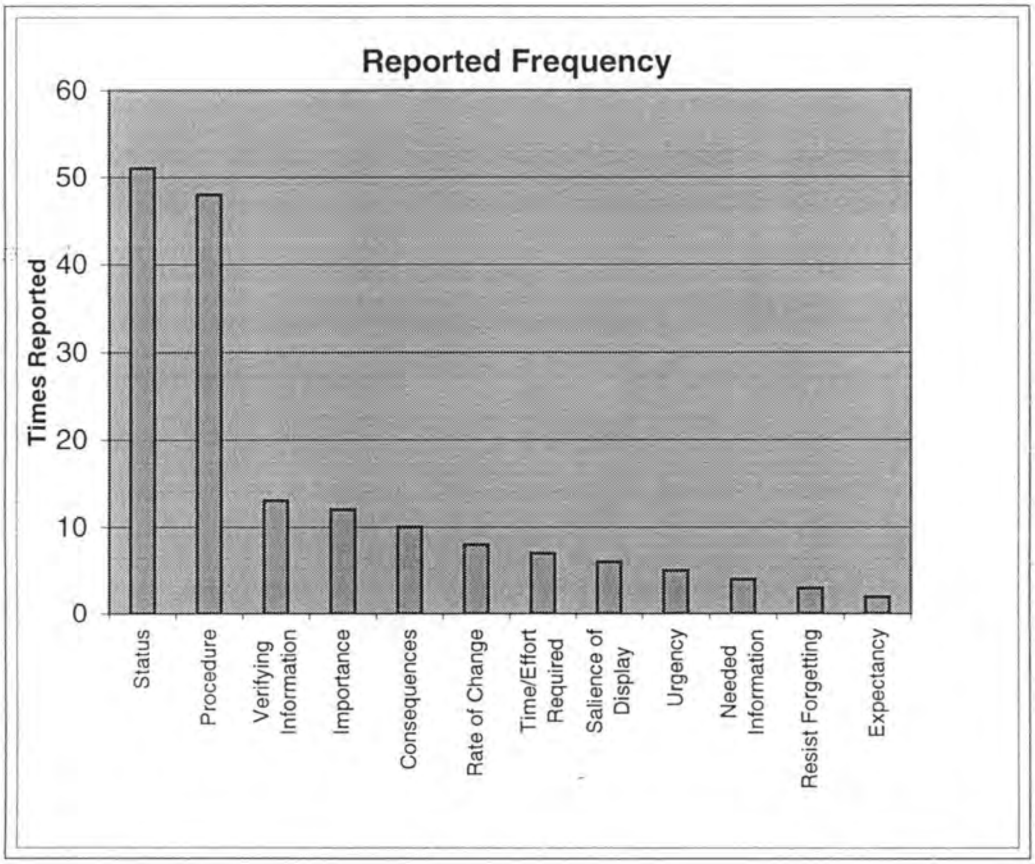


Figure 4.4 Reported Frequency of Factor That Affect Task Prioritization.

Significance Testing

Prioritization Factors

Due to the nature of the cognitive interviewing technique, traditional analysis of variance on the reported prioritization factors was not appropriate (Montgomery, 1997; Ostle, 1963). Therefore, an analysis was performed to determine if the frequency with which each factor was reported showed statistically significant differences from the other factors. A chi-square test for counted data was applied to the results presented above. In this analysis, the null hypothesis states that all factors are equally likely. A rejection of the null hypothesis accepts that the observed frequencies are not equally likely in each of the 12 factor categories (Devore, 1987).

The chi-square statistic from this analysis had a value of 223.02 with 11 degrees of freedom, resulting in rejection of the null hypothesis ($p < .001$). In other words, there is very strong evidence that the observed values do not come from a distribution where frequencies in each factor category are equally likely.

Since the status and procedure factors had such high frequencies compared to the other prioritization factors, these two factors were removed and a the chi-square test was performed on the remaining 10 factors. This test had a chi-square value of 18.00 with 9 degrees of freedom, resulting in rejection of the null hypothesis ($p < .05$). Thus, even with the high frequency factors removed, there is strong evidence that the remaining factors are not equally likely.

Elicitation Technique

The prioritization factors broken down by the elicitation technique is presented in Table 4.5. A primary question of this study was to determine if the intrusive and retrospective techniques give significantly different results in data collection. In order to determine if there was a significant difference in the frequency of factors reported between the two techniques, a chi-square test was applied to the 2 x 9 matrix in Table 4.5.

In this application of the chi-square test, the null hypothesis is the assumption that the two rows come from the same distribution. If we fail to reject the null hypothesis, then the conclusion is made that the two rows are not significantly different.

The chi-square statistic from this analysis had a value of 4.36 (df = 11, p = 0.9583). Thus we fail to reject the null hypothesis and we conclude that the intrusive and retrospective elicitation techniques do not result in different results.

	Status	Procedure	Verifying Informatior	Importance	Consequences	Rate of Change	Time/Effort Required	Salience of Display	Urgency	Needed Information	Resist Forgetting	Expectancy
Intrusive	21	25	5	2	1	4	6	4	2	4	1	1
Retrospective	27	26	3	2	4	8	7	3	4	6	2	1

Table 4.5 Prioritization factors by Elicitation Technique.

Event Effect

Another concern with the nature of this experiment is the use of the three event types (scenario, ATC and malfunction). Perhaps the prioritization factors depended upon which event was probed. Table 4.6 presents the summary of prioritization factors reported by event type.

	Status	Procedure	Verifying Informatior	Importance	Consequences	Rate of Change	Time/Effort Required	Salience of Display	Urgency	Needed Information	Resist Forgetting	Expectancy
Event 1 (Scenario)	12	10	1	1	1	1	1	0	0	1	0	0
Event 2 (ATC)	9	6	2	0	1	2	2	0	1	2	3	0
Event 3 (Malfunction)	6	9	2	0	1	4	1	2	0	2	0	0
Event 4 (ATC)	8	9	1	1	0	3	2	1	0	2	0	0
Event 5 (Scenario)	14	16	2	0	0	2	5	0	0	2	0	2
Event 6 (Malfunction)	11	13	2	4	1	2	5	2	4	2	0	1
All Scenario	26	26	3	1	1	3	6	0	0	3	0	2
All ATC	17	15	3	1	1	5	4	1	1	4	3	0
All Malfunction	17	22	4	4	2	6	6	4	4	4	0	1

Table 4.6 Prioritization factors by Event Type.

The chi-square statistic from the individual breakdown of the 6 events was 62.35 (df = 55, p = .2312). Thus, we fail to reject the null hypothesis and conclude that there is no statistical difference in the reporting of prioritization factors between the 6 events.

Additionally, the chi-square statistic from the three event types was 26.13 (df = 22, p = .2461). Again, we fail to reject the null hypothesis, and conclude that the prioritization factors are independent of the event type.

Scenario Effect

To determine if the two different scenarios had an effect on prioritization factors reported by the pilots, the frequencies were summed over the Bravo and Sierra scenarios (see Table 4.7).

	Status	Procedure	Verifying Information	Importance	Consequences	Rate of Change	Time/Effort Required	Salience of Display	Urgency	Needed Information	Resist Forgetting	Expectancy
Bravo	23	23	5	1	2	7	8	3	3	6	0	1
Sierra	25	28	3	3	3	5	5	4	3	4	3	1

Table 4.7 Prioritization factors by Scenario.

The chi-square statistic from this analysis had a value of 6.70 (df = 11, p = 0.8228). We fail to reject the null hypothesis and conclude that there is no statistical difference between the bravo and sierra scenarios.

Timing Effect

Half of the probes were performed before a critical event and half after the event. To determine if the timing of the probe had an effect on the reporting of prioritization factors, the data was organized into Table 4.8, showing the timing of the probes before and after an event.

	Status	Procedure	Verifying Information	Importance	Consequences	Rate of Change	Time/Effort Required	Salience of Display	Urgency	Needed Information	Resist Forgetting	Expectancy
After	23	22	5	1	2	8	6	5	5	5	3	0
Before	25	29	3	3	3	4	7	2	1	5	0	2

Table 4.8 Prioritization factors by Timing (Before/After).

The chi-square statistic from this analysis had a value of 13.10 (df = 11, p = 0.2868). Again, we reject the null hypothesis and conclude that there is no statistical difference between the before and after event timing of the probe.

Discussion

This study was an initial attempt to identify the factors that affect task prioritization. The task environment required pilots to fly realistic, published arrivals in a part-task simulator. The method of prioritization factor elicitation was the cognitive interview using either the retrospective or intrusive technique.

Status and procedure emerged as the two factors most reported by pilots. Additionally, verifying information, task importance and consequences of not performing task showed a substantial frequency of reporting. Statistical tests confirmed that significant differences in the frequency of factor reporting were present and that there were no significant differences in the frequency of reporting for the elicitation technique (intrusive/retrospective), scenario flown (Bravo/Sierra) or the timing of the probe questioning (before/after).

The Prioritization Factors

Data analysis for this study presented a very challenging task for the author. The nature of the data collected was rich with insights into how pilots prioritize tasks, perform multiple concurrent tasks and, in general, make decisions on the flight deck. However, with such rich and complex data, interpretation and classification of pilot responses is, to say the least, very difficult.

In the next several paragraphs, a more detailed description of the prioritization factors is presented. While none of these descriptions are direct quotes from the pilots, they represent the pilot's justifications of how task prioritization was accomplished. They are presented in rank order of number of times reported.

Status – The ***perceived*** status of the current task was unsatisfactory, so it was currently being performed to bring its status to a satisfactory level. For instance, the pilot may have an assigned altitude of 15,000 feet. If the pilot were to find himself at an altitude of 100 feet or more below the clearance, it would result in the pilot consciously focusing on the task to reduce the deviation and get back to the assigned altitude. Similarly, if the status of high priority tasks, such as the aviate tasks, were satisfactory, then attention could be allocated to other, non-critical tasks.

Procedure – The reason the current task was being performed was because it was the proper task to execute in the current context. For instance, if an ATC instruction was given to descend to a particular altitude then the task was performed immediately. The relationship between ATC and pilots is one that ATC issues clearances and pilots follow those clearances. Similarly, when the filed flight plan required a turn at a navigational waypoint, then when that waypoint was reached, the turn was initiated. It was the procedure that needed to be followed in order to perform the duties of a pilot.

Verifying Information – Often, a pilot will perform a task, then immediately perform an additional task with the purpose of verifying that the initial task was accomplished. For instance, during the arrival, a pilot may initiate and complete a turn at a particular navigational waypoint. Upon completion of the turn, he will switch his attention from the Primary Fight Display (PFD), to the Navigational Display (ND) to verify that the information regarding his heading obtained from the PFD is verified by the information on the ND. It could be argued that this sequence of events is in fact all part of the same task (monitoring and controlling heading). However, the approach taken in this study assumed that a change from one display to another constituted a task switch. Ultimately, this level of specificity in the task analysis would address this concern. In the task analysis adopted for this study, the above example would represent a move from a primary aviate task to a task classified under the navigate category.

Importance – The importance of a task, relative to other competing tasks, determines where a pilot will focus his attention. There were many instances were the pilot reported that he was "flying the airplane first." In other words, he was attending to the primary aviate tasks of monitoring and controlling heading, altitude and speed which took precedence over other tasks, such as performing checklists, planning ahead or determining current position on the arrival. Pilots are very familiar with the ANCS ordering of tasks and strive to adhere to its hierarchy. It should be noted that a pilot's response would not be categorized in this factor unless the pilot explicitly stated, "this task was more important than the others."

Consequences - Pilots reported the consequences of not performing the task and safety considerations associated with performing tasks. For instance, the consequences of not maintaining the assigned altitude could result in conflict with other aircraft or terrain.

Rate of change - When the status of a task is currently changing at a significant rate, the pilot tends to stay with that task until it is once again stabilized. For example, in a turn, where the heading of the aircraft is changing, pilots will closely monitor the progress of the task until they finish the turn and level the wings. They realize that if they were to divert their attention to another task, that upon returning to the task, it may have progressed to a status that is very unsatisfactory (a turn past their desired heading).

Time/Effort Required – Pilots reported that they evaluated the time and/or effort required to perform tasks and made decisions regarding which task to perform upon these evaluations. It is interesting to note that some pilots selected the quick/easy task to perform first, while others selected the task that would take considerable time/effort to perform first.

Salience of Stimulus – When there is a sudden, obvious change in a visual display, the pilots often switched their attention to the change, and at least, acknowledged its presence. For instance, this might occur when an equipment malfunction event was activated and the yellow caution light was illuminated along with a message on the EICAS display. It was interesting to note that the switch of attention was often very quick, to acknowledge the change, but then their attention was directed right back again to the task that was in progress when the visual change occurred. In the interviews, they often talked about their conscious evaluation of the meaning of the change, their realization that the priority of the associated task was not greater than the currently active task, so they returned to the original task.

Urgency – The urgency of a task is defined as the time it will take to complete a task in relation to the time until the task needs to be completed. Pilots are very aware of high workload situations, and continually try to "stay ahead of the airplane" by performing tasks as early as possible. However, in certain situations, tasks cannot be performed early and thus, take on urgency. Pilots reported currently performing a task because it needed to be completed in the very near future.

Needed information – Pilots reported the reason they were attending to a particular task was that its displays contained needed information. For example, when pilots were probed as to why they were monitoring the attitude indicator, their reply would be that it was the source information they needed in order to maintain heading and altitude.

Resist Forgetting – This factor was directly related to compliance with ATC clearances. Upon receiving an instruction from ATC, the pilots immediately began to give control inputs to the aircraft (usually the mode control panel), even before acknowledging the clearance with ATC. When prompted as to why they began immediate inputs, their reply was that they tended to forget clearances unless they immediately input the clearances into the mode control panel.

Expectancy – Pilots often tried to perform tasks well in advance of when they needed to be performed. Their justification for attending to such a task was that they were expecting a high workload in the near future, so they were attempting to get as much as possible done early so that they had more time to deal with the tasks during the high workload period. This is very consistent with strategic task management (Schutte and Trujillo, 1996), strategic workload management (Hart, 1989; Adams, et al, 1991; Raby and Wickens, 1994) and occurs in times of low workload, which was not frequency encountered in this experiment.

Comparison to predictions

Recall from the introduction that although no studies have produced data on the prioritization of flight tasks, the literature suggests 13 possible factors that affect task prioritization. The current section evaluates the commonality between those predictions and what was empirically collected in this study.

Table 4.9 compares the predicted factors with the factors reported by the pilots in this study. It is reassuring to find that the most reported factor, status, was in fact predicted in the literature along with several other factors, such as importance, time/effort required and a few other less frequently reported factors.

Factors Predicted In The Literature	Corresponding Factors Identified in this Study
Advance knowledge of upcoming tasks	Expectancy
Discriminability of task-related stimuli	(none)
Differences in level of effort required to process task-related stimuli	Time/Effort Required
Temporal proximity of task-related stimuli	(none)
Task importance: aviate > navigate > communication > manage systems	Importance
Perceived urgency of task (time remaining vs. time to complete)	Urgency
Task difficulty	Time/Effort Required
(automation) task proficiency	Time/Effort Required
task recency	(none)
task momentum: tendency to continue to perform the current task	(none)
task proximity to completion	(none)
amount of effort already invested in tasks	(none)
perceived task status (satisfactory, unsatisfactory)	Status

Table 4.9 Comparison of Predicted Factors to Reported Factors.

However, a factor not predicted, procedure, was very apparent in the pilot's reporting of prioritization factors. This is puzzling because for pilots, this was a very intuitive and obvious justification as to what task was currently being performed. During a probe, when the pilot was performing a task that was required to fly the scenario, such as turning the aircraft to the proper heading at a navigational waypoint, the pilot's justification for performing that task was to the effect, "The current situation requires that I perform this task right now." When probed deeper, often the pilots could not verbalize any other reason for attending to the task other than the procedure of flying demanded that the task be performed at that point in time.

Another factor, importance, predicted in the literature, was explicitly reported only 7% in this study. However, the ANCS task hierarchy is well known by pilots, and practiced rigorously. In fact, during the probes, the primary aviate tasks were reported as the current task more than 80% of the time. It was surprising that the importance factor did not appear more frequently in the probes. Perhaps this factor is such a significant part of a pilot's routine behaviors and decision making that it has taken on tacit knowledge characteristics, and it not consciously processed by pilots. Therefore, although it may affect how a pilot prioritizes tasks, he does not explicitly realize its influence and is therefore unable to report it verbally during a probe. Again, it should be noted that during data analysis, pilots would have to report that one task was "more important" than another task for the importance factor to be identified.

Reduction of Prioritization Factors

In the present section, the effort is directed at given meaning to the factors reported by the pilots. Upon reflection on the prioritization factors presented earlier, it is readily apparent that there exist relationships between the factors. Recall, however, that the objective of the data analysis was to classify what the pilots reported and not an attempt to infer what the pilots really meant.

Status

The single most reported factor in this study was status. Pilots reported that the current unsatisfactory (or satisfactory) status of a task at least partially determined why the current task was the focus of attention. Rate of change of task status was reported as a separate factor, but this is closely related to status. It is known by the pilots that if they were to divert attention away from a task while its status is rapidly changing, it is possible that upon returning to the task, it will have an unsatisfactory status.

Verifying information is a crosscheck to reassure that what one source of status information reports is consistent with another information source. Therefore, verifying information is consistent with the status factor.

On the flight deck, many of the displays do not have excessively salient stimuli. For instance, the altitude display on the Primary Flight Display (PFD) is continually changing and appears very much the same if the altitude reading is 35,000 ft. or 100 ft. However, the status and warning indicators and EICAS message display areas are designed with the intent of capturing attention when information is available that the pilot needs to be informed about, such as exceeding aircraft limitations or equipment malfunctions. If the aircraft were to descent below 500 ft. without being configured for landing (gear down, flaps extended, etc.), the altitude display on the PFD merely displayed the altitude. However, the red warning light would flash and an EICAS message that alerts the pilot to an unsafe condition was displayed. In essence, the warning light and EICAS message are delivering status information about the aircraft or subsystems, so the factor salience of stimulus is related to the status factor.

Urgency also appears to be related to status. When a task is very urgent, its status will need to be complete or satisfactory in a relatively short time. As an extreme example, if vertical speed of the aircraft is –1500 ft./min. and the altitude of the aircraft is 1500 ft. above ground level, the status of the altitude task is satisfactory for the moment. However, after 30 seconds, the urgency of the altitude task is beginning to increase. If the pilot does not respond and give control inputs rather quickly, then the status of the altitude task will become severely unsatisfactory in a very short time.

Finally, needed information, although reported very infrequently also appears to be status related. When a pilot stated that that he was attending to a task because it was the source of needed information, he was after the information to determine a status parameter of the aircraft.

So the factors rate of change, verifying information, salience of stimulus, urgency and needed information are all related to the general prioritization factor status and is visually depicted in Figure 4.5.

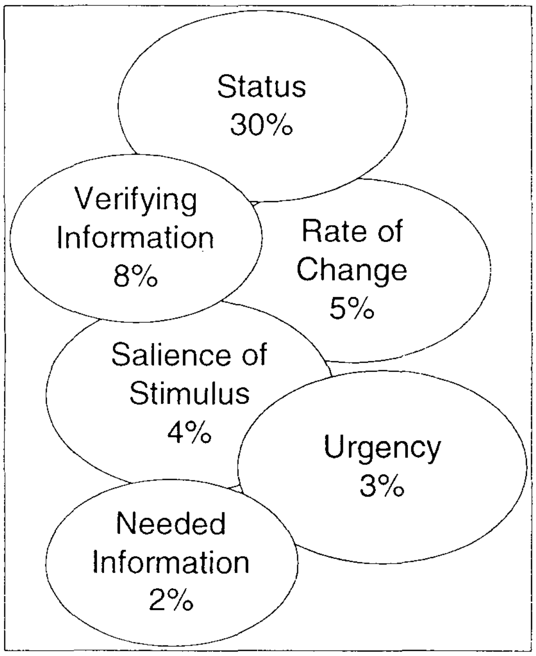


Figure 4.5 The General Status Prioritization Factor (52%).

Procedure

During the interviews, pilots reported that the reason they were performing the current task was because it was the correct procedure to execute at the current time and in the current context. This appears to be a very intuitive and obvious justification of current task focus, however, upon closer examination, this may be the most complex factor identified in this study.

There are at least two dimensions to the procedure factor. First, there is an externally driven dimension, where the pilot waits for external cues from the environment to initiate a task. For example, if the pilot has an ATC instruction to turn the aircraft to a heading when it reaches a navigational waypoint, then when the aircraft reaches the waypoint, the pilot initiates the procedure and turns the aircraft. He follows the procedure when the environmental cue is encountered.

However, the representation of procedural knowledge in the mind is very much an internal dimension of the procedure factor. Exactly how humans represent, store and recall this type of knowledge is a research area with much activity, yet there is no consistent agreement on how this process functions (Anderson and Lebiere, 1999). Additionally, interactions between procedural knowledge and memory systems (long term and short term) do not have exact, widely accepted theory (NRC, 1998). To understand this internal dimension might equate to an overall theory of human cognitive processing.

Another factor reported by pilots was the expectancy of upcoming events. The pilots were searching for opportunities to perform anticipated procedures at an earlier time in the flight scenario. This suggests a link to the procedure factor.

The resist forgetting factor and the time/effort factor appear closely linked for the following reason. In the simulator, when the pilot was issued a clearance by ATC (simulated by the experimenter), he was handed a slip of paper with the clearance. The purpose of the slip was to allow the pilot to continue flying and not require him to write down clearances. If the pilot were to forget the clearance, he merely needed to glance down at the slip to again read the clearance. So the pilot's justification of performing the task to avoid forgetting it is really an attempt at reducing the time and effort of performing the task. Similarly on the actual flight deck, the pilot has several resources available if he were to forget a clearance. He could ask his copilot for the information (small time/effort investment) or he could contact ATC again to obtain the information (a substantial time/effort investment).

Further, the time/effort factor is an evaluation of the procedure to be performed and an estimation of the requirements to perform the task. Therefore, it is suggested that the time/effort factor is related to the procedure factor.

Therefore, a second general factor labeled status is suggested, with the sub-factors expectancy, time/effort required and resists forgetting configured as in Figure 4.6.

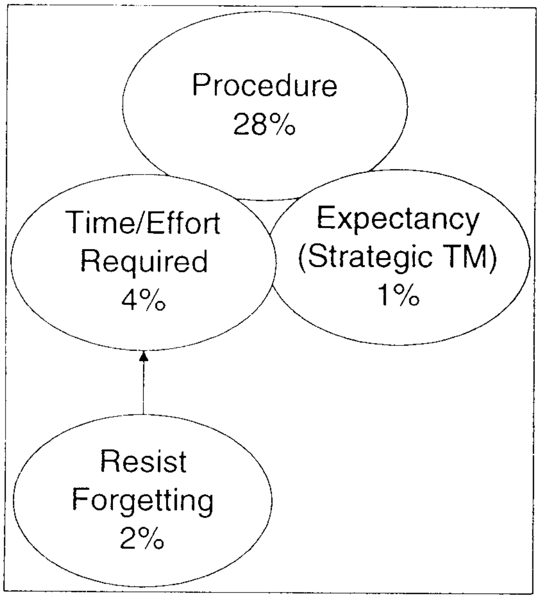


Figure 4.6 The General Procedure Prioritization Factor (35%).

Value

The two factors importance and consequences of not performing a task are closely related. To a pilot, a task is important if failing to perform it jeopardizes the safety of the aircraft or passengers, violates FAA regulations or fails to comply with ATC clearances. When the pilots reported the consequences of not performing a task in the interviews, they were mostly concerned with safety and non-compliance implications.

The general prioritization factor proposed that encompass importance and consequences is labeled value, and presented in Figure 4.7. It can be conceptualized as the value or worth of performing the task towards reaching the goal or subgoals of the flight.

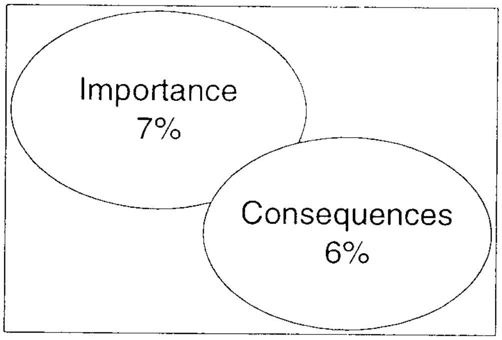


Figure 4.7 The General Value Prioritization Factor (13%).

For example, if the overall mission goal of a flight is to deliver the passengers to the intended destination safely, quickly and comfortably, then subgoals of the mission might be decomposed into such goals as comply with ATC clearances and avoid exceeding aircraft performance limitations. Using the general prioritization factor then, pilots consider the value of performing a task as they determine their prioritization strategy while flying.

Similar to the general procedure factor, the value factor has internal representations that are not obvious or sharply defined. For example, when a pilot is challenged with the decision to comply with an ATC-instructed altitude change and a significant equipment malfunction simultaneously, which has a higher value? Failure to comply with ATC may result in an unsafe conflict with other aircraft or terrain, but failure to deal with a critical equipment malfunction may also escalate into a situation where the aircraft becomes no longer flyable. It is in these situations that a pilot's knowledge, including training and experience, emerge to assign value to the tasks and prioritize in such a way as to meet the overall mission goals.

A Model of Task Prioritization

The discussion presented above identifies three general categories of prioritization factors: status, procedure and value. These three general categories incorporate all twelve of the specific factors identified in the interviews of the pilots.

While three distinct general factors emerge, there appears to be a logical relationship between them. The status factor represents the current state of the world. The value factor represents the desired state of the world or simply the goal state. The goal state is the pilot's understanding and internal representation of what state the system needs to be in for the mission goals to be met. Finally, the general procedure factor is the link between the current state and the goal state. In other words, the pilot, operating the system in the current state, uses procedures to obtain the goal state. Figure 4.8 graphically presents this model of task prioritization.

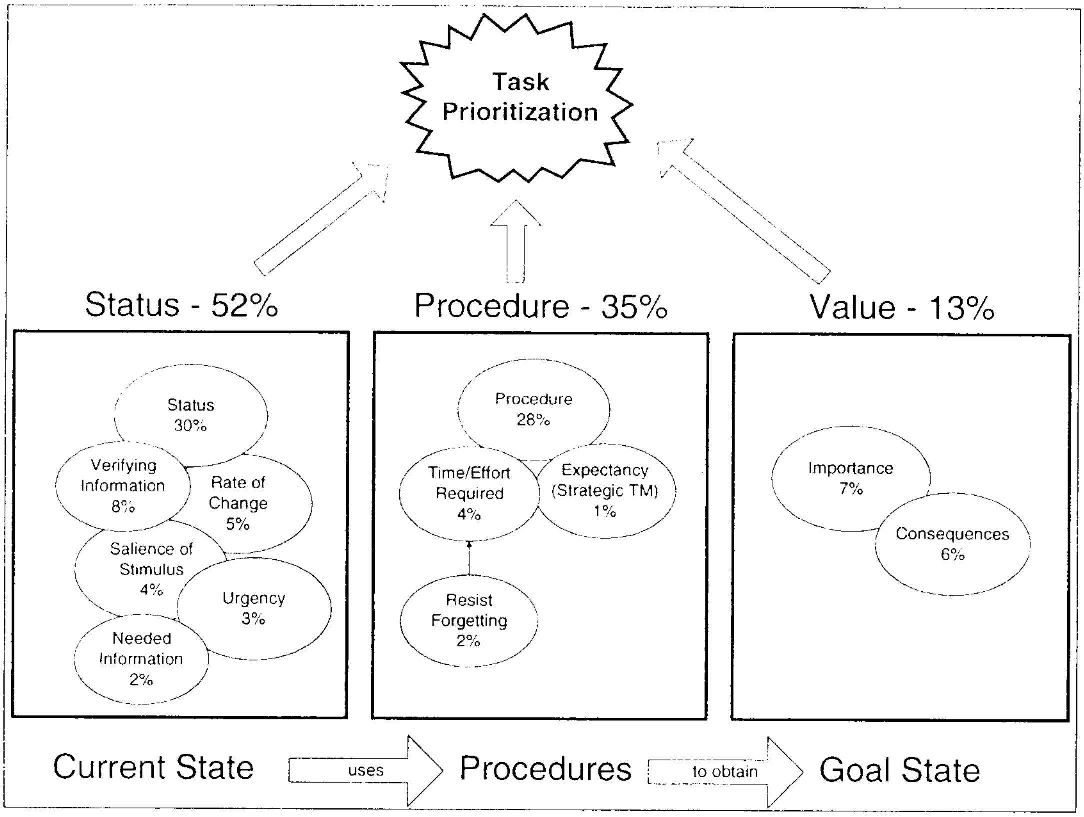


Figure 4.8 The Model of Task Prioritization.

In this model, the task prioritization process is driven by three general factors status (52%), procedure (35%) and value (13%). It should be noted that the weighting of the factors is preliminary and is based on the relatively limited data collected in this experiment.

The relationship between the value and procedure factors may be closely intertwined. In a normative theory, the development of the procedures is based on the value of performing the tasks. In other words, the procedures are a sequence of tasks that are performed in the order of the highest value. Therefore, the value of performing the task is inherent to the procedures that pilots perform on the flight deck. To a certain extent, the pilots realize this, and they are confident that if they perform the procedures the important tasks will be attended to and the consequences of not performing tasks will be minimized. Simply stated, the pilots trust the procedures.

Limitations

A fundamental limitation of this study deals with the nature of task prioritization. In this study, we relied on the pilot's verbalization of the prioritization process to obtain a sense of how task prioritization is accomplished. If, in fact, prioritization is an accessible, explicit behavior, than it is likely that this study was able to record and analyze at least part of those factors that affect task prioritization. However, if task prioritization is truly an implicit, unconscious process that pilots are not able to explicitly identify, then this study falls short of its expectations. Until researchers make further gains in an overall better understanding of human cognition and are able to identify which mental processes are explicitly accessible, this fundamental question will go unanswered. At this time, we continue with the assumption that task prioritization is, at least, partially an explicit process that pilots can identify and discuss.

Another limitation is the possibility of experimenter bias. The entire study was developed, performed and analyzed by the author. Every attempt was made to approach all data collection and analysis from a neutral perspective and not to succumb to a confirmation bias associated with expectancies of task prioritization factors. The author is confident in his neutral approach, however only additional research that generates supportive evidence of the findings in this experiment would truly eliminate this possible limitation.

As with all laboratory experiments, this study had limitations of ecological validity. It is true that the simulator used in this study was a single pilot, part-task simulator that differs greatly from the real world flight deck, which includes two pilots in an operational setting. However, the objective of the simulator was to put the pilots in the frame of mind of flying a published arrival and to challenge them with real-world thought processes and decision making. In the post-test questionnaire, each pilot expressed that the part-task simulator was successful in that respect, and they found themselves thinking like a pilot and performing the tasks present in the operational environment.

One opportunity for improvement associated with the simulator environment would be to present more challenging instances where task prioritization occurs. In this study, there were relatively few instances where the pilot was truly overloaded and had to prioritize more than 3 tasks. In other words, workload levels were always manageable and the consequences associated with the relatively minor equipment malfunctions were too insignificant. For future experiments, it is suggested that more non-aviate tasks be placed on the pilot in addition to more severe equipment malfunctions, where the consequences might be much more detrimental than in the current experiment.

Conclusions

The primary objective of this study was to identify factors that affect prioritization. Analysis of the pilot interviews resulted in 12 factors that were subsequently reduced to the three general prioritization factors of status, procedure and value. These factors formed the basis of a model of task prioritization (Figure 4.8).

With this model, we believe we have at least a preliminary understanding of task prioritization. However, because this study was essentially a hypothesis generation exercise, we are now tasked with developing further studies to support and refine the findings presented here.

The ultimate goal of the present research is twofold. First, with a better understanding of the prioritization process, perhaps training techniques can be developed that explain this process to pilots and explicitly emphasize how experts perform task prioritization, with the objective of modifying inexperienced pilot behavior to be more consistent with the behaviors observed in experienced pilots.

Secondly, the realization that the general status factor had such a major influence on the prioritization process is supportive of use of pilot aids that assist the pilot in enhancing situation awareness of the current state of the aircraft. Even if these aids are not destined for use in the operational flight deck, again, perhaps they can be employed in a training role to help pilots better prioritize tasks.

A secondary, methodological objective of this study was to evaluate elicitation techniques. In this study, we used both the intrusive and retrospective techniques and could determine no difference in the data that was collected with the techniques. Therefore, we conclude that in future studies, we can elect to utilize the technique that will best facilitate the study.

CHAPTER 5:
FURTHER INVESTIGATION OF FACTORS THAT AFFECT TASK PRIORITIZATION ON THE FLIGHT DECK

Introduction

The objective of the second study was to further investigate the pilots' use of a subset of prioritization factors identified in Chapter 4 (Figure 4.8). Pilots flew final approach procedures on a part-task simulator. The retrospective interviewing technique, in coordination with a Challenge Probe Point (CPP) questionnaire was used to probe subjects for factors that influenced their task prioritization strategy. Additionally, task performance data was collected and analyzed with the objective of identifying a relationship between task performance and prioritization factors used by pilots.

Method

Participants

The participants for this study were 8 airline pilots, all male, with an average of 6838 total flying hours. They had an average of 2531 hours of single pilot time and 481 hours of "glass cockpit" experience. Their age range was 25 to 52, with an average of 34.6 years. They were paid a stipend and travel expenses for their participation in the study.

Equipment

The part-task simulator was the NASA Stone-Soup Simulator version 4.1 obtained from NASA-Ames Research Center. The hardware consisted of 3 SGI Indigo2 workstations, running the IRIX 6.2 operating system. The workstations were networked together, two for pilot displays and the other for the experimenter control of the simulator. The simulator flight control was performed with a B&G

Systems Flybox and 2 mice connected to the pilot's workstations. Video equipment included a Panasonic 8mm camcorder, Sony PVM-1910 video monitor, Videonics MX-1 video mixer to obtain the picture-in-picture configuration. Video from the pilot's workstation was achieved using an SGI Galileo Video board and software for NSTC video output.

Experiment Structure

Data collection for the experiment consisted of four flight scenarios, designated as Standard, A, B, and C (Figures 5.1, 5.2, 5.3, 5.4). These were all variations of the same arrival scenario, with the differences existing in the Challenge Probe Point (CPP) of a particular scenario. A CPP was an operational situation during the scenario where up to 6 tasks could become active at the same instant. The pilot had to decide the order in which the tasks were to be performed, then actually perform the tasks. For example, in scenario A (Figure 5.2), the CPP was located at the SUNOL intersection, and was the focus of data collection for this scenario. At SUNOL, an ATC call was initiated, giving a speed clearance. Additionally, an engine fire was initiated, requiring the pilot to perform an engine fire checklist. The pilot was faced with the following 6 concurrent tasks that all required attention:

1. initiate a descent to 4000'
2. initiate a turn to a heading of 240
3. respond to an ATC instruction to reduce speed to reduce speed to 180 knots
4. reduce the aircraft's speed to 180 knots
5. perform the engine fire checklist
6. configure the displays for the ILS

Scenarios B and C also contained similar CPP's intended for data collection. The Standard scenario (Figure 5.1) does not include a CPP, and was used as a measurement of baseline performance for the pilot. The order that subjects flew the four scenarios was a four by four Latin square design replicated 2 times (Montgomery, 1997). This effort was an attempt to ensure that the learning effects of order on the performance data were counterbalanced.

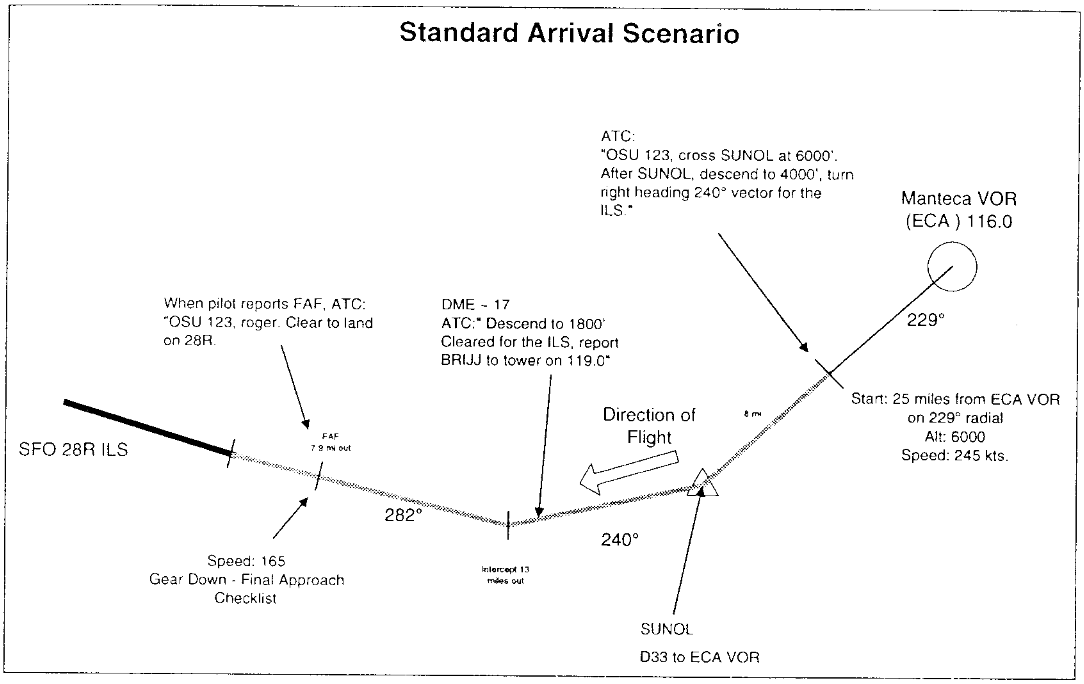


Figure 5.1 Standard Scenario.

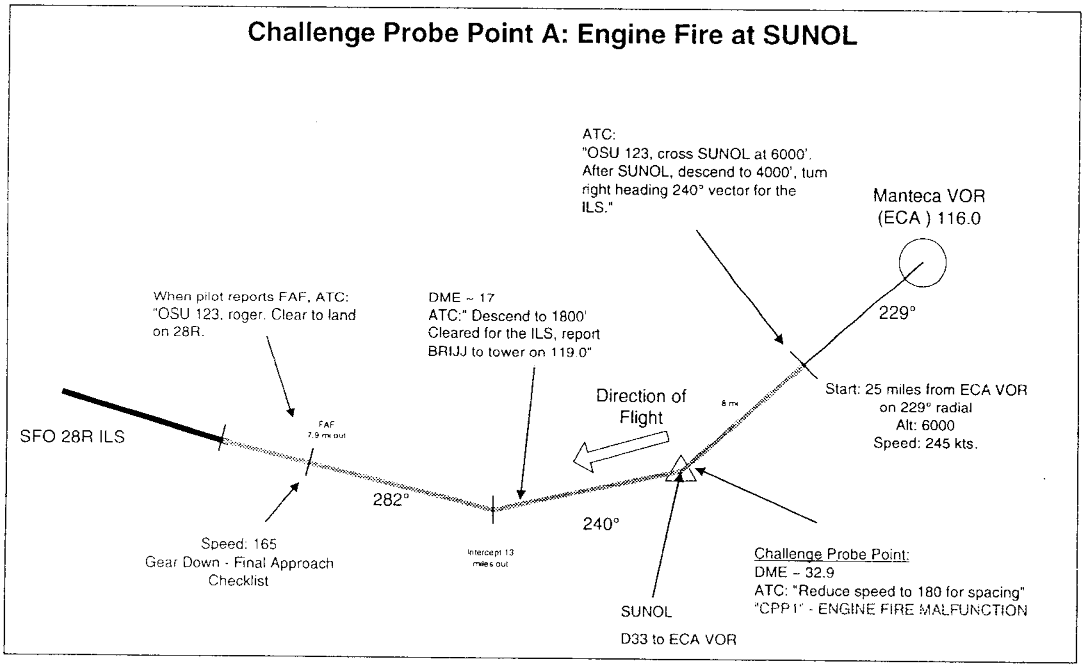


Figure 5.2 Scenario-A.

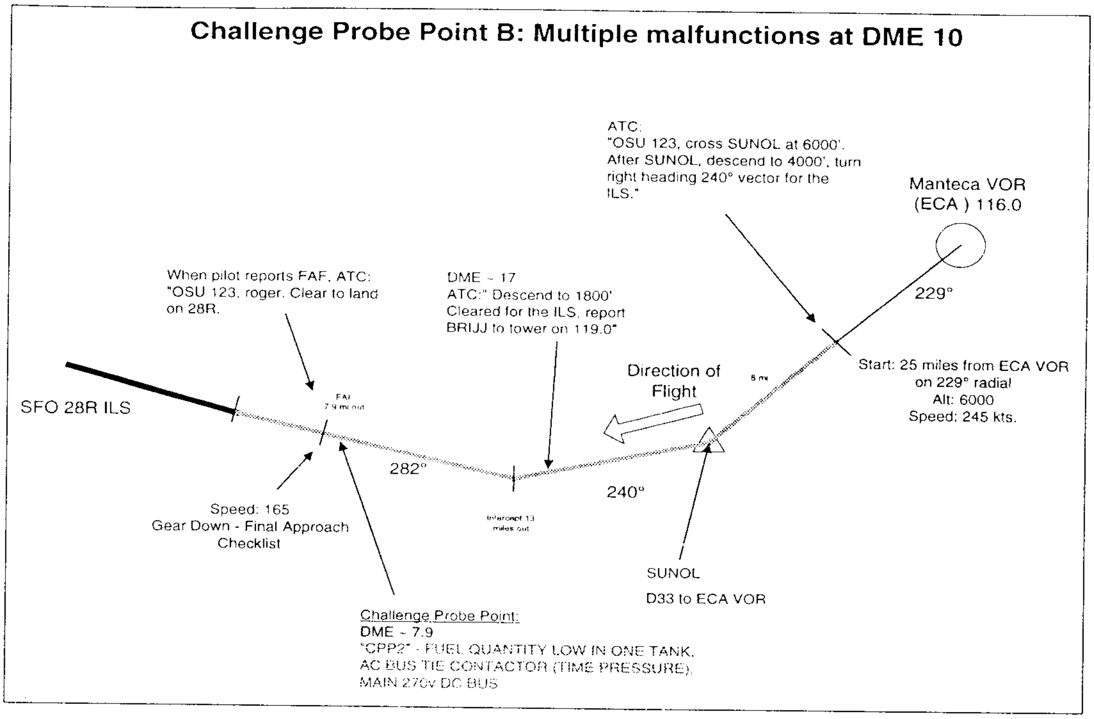


Figure 5.3 Scenario-B.

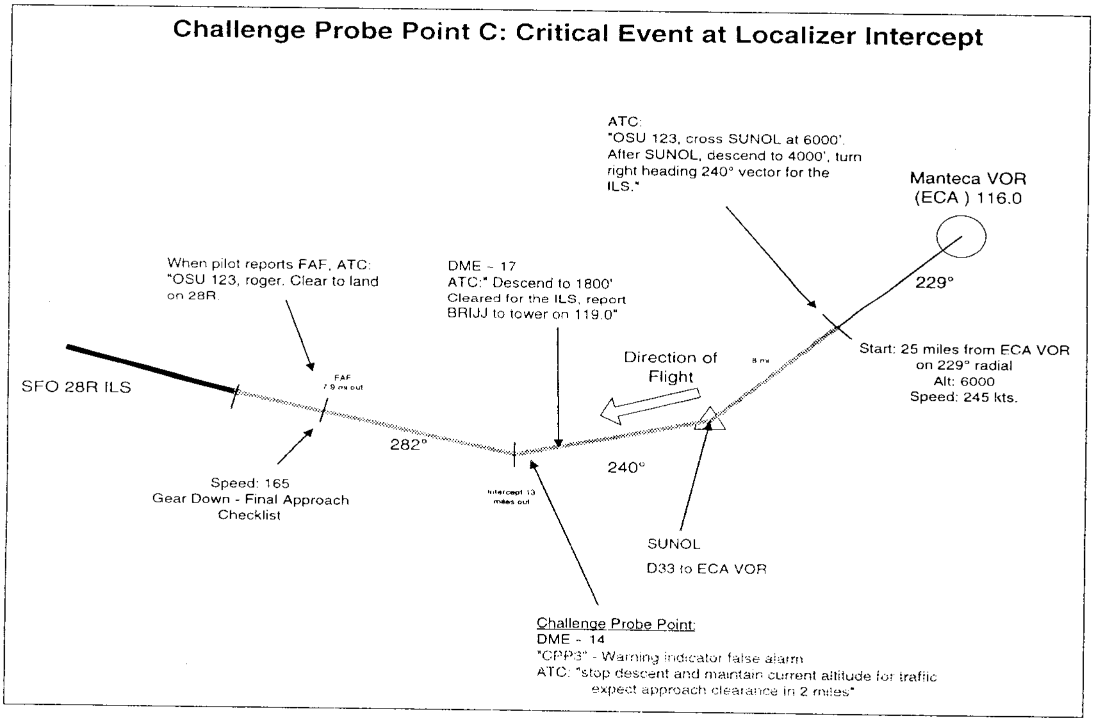


Figure 5.4 Scenario-C.

Challenge Probe Point (CPP) Questionnaire

In each scenario, the retrospective interviewing technique was the knowledge elicitation method used to collect task prioritization data (Salter, 1988; Cooke, 1994). This technique was selected for its low intrusiveness, ease of application and as a result of the study in Chapter 4, where it was found that no differences existed between the intrusive and retrospective techniques in eliciting information from the pilots regarding task prioritization factors.

A very common approach to designing subjective questionnaires is the Likert scale (Friedenberg, 1995). A Likert scale typically consists of a number of statements to which subjects respond on a five-point scale of agreement to disagreement, approval to disapproval, or favorable to unfavorable, depending on how the statement is worded (Graham and Lilly, 1984).

A CPP Questionnaire was developed for each of the 3 scenarios that contained a CPP and can be found in Appendix 5. Each questionnaire contained three sections. First, the pilot was asked the order in which the 6 tasks were actually performed. Next, the pilot was presented with a set of statements regarding the factors that were used to determine the priority that was assigned to three specific tasks. The pilot responded to this Likert-type statement (Graham and Lilly, 1984) with: Strongly Agree, Agree, N/A (not applicable in the current context), Disagree or Strongly Disagree. For each of these statements, the pilot evaluated, in retrospect if his use of this factor was appropriate then was given an opportunity to make any comments regarding the statement or its appropriateness. The third section of the questionnaire gave the pilot an opportunity to re-order the 6 tasks, then justify why he performed the tasks in such an order. The pilot could also decline the opportunity to reorder the tasks if he was comfortable with the order in which he actually performed them.

The model of task prioritization presented in Chapter 4 includes 12 factors that affect task prioritization (Figure 4.8). These 12 factors are the result of pilots verbalizing factors that were used in the prioritization of tasks. In the present study, a subset of these 12 factors was selected for further investigation on the basis of their frequency of reporting in the earlier study. The 6 factors included in the present study are ***status, procedure, value, urgency, salience*** and ***time/effort*** (for a thorough explanation of these factors, see Chapter 4).

Additionally, a subset of the 6 tasks associated with each CPP was selected for investigation using the questionnaires. At each CPP, exactly 3 tasks were probed for the factors that affected the order in which that the tasks were performed. The tasks were selected based on their associated classification under the Aviate-Navigate-Communicate-Manage Systems (ANCS) classification taxonomy common in both the pilot and research communities. Tasks were selected at each CPP with ANCS classifications. For example, in CPP-A, Navigate, Communicate and Manage Systems tasks were selected for inclusion in the probe questionnaire.

This resulted in the formulation of a 6-factor by 9-task matrix of datapoints. This was the basis for the 54 statements that probed the factors that affect task prioritization, which made up the second section of the CPP questionnaire. Table 5.1 is the structure for the design of these statements. For example, in CPP-A, the statement regarding the status factor of the "perform engine fire checklist" task (statement A3-1 from table 5.1) was the following:

> *I performed the engine fire checklist when I did was because I judged it to be the task farthest from satisfactory completion. (A3-1)*

At each CPP, 6 statements for each of 3 tasks was posed to the subjects, who responded with their agreement/disagreement to the statement. The subjects' response to these statements was the dependent variable in the present study, and provided the evidence for the use of the proposed factors that affect task prioritization.

	Factors that Affect Task Prioritization					
CPP-A Tasks	Status	Procedure	Value	Urgency	Salience	Time/Effort
Navigate: InitiateTurn	A1-1	A1-2	A1-3	A1-4	A1-5	A1-6
Communicate: Respond to ATC	A2-1	A2-2	A2-3	A2-4	A2-5	A2-6
Manage Systems: Perform Engine Fire Checklist	A3-1	A3-2	A3-3	A3-4	A3-5	A3-6
CPP-B Tasks	Status	Procedure	Value	Urgency	Salience	Time/Effort
Navigate: Track Localizer and G/S	B1-1	B1-2	B1-3	B1-4	B1-5	B1-6
Communicate: Report FAF to ATC	B2-1	B2-2	B2-3	B2-4	B2-5	B2-6
Manage Systems: Perform Bus Tie Contactor Checklist	B3-1	B3-2	B3-3	B3-4	B3-5	B3-6
CPP-C Tasks	Status	Procedure	Value	Urgency	Salience	Time/Effort
Aviate: Stop descent for traffic	C1-1	C1-2	C1-3	C1-4	C1-5	C1-6
Navigate: Intercept the Localizer	C2-1	C2-2	C2-3	C2-4	C2-5	C2-6
Manage Systems: Attend to Master Warning Light	C3-1	C3-2	C3-3	C3-4	C3-5	C3-6

Table 5.1 CPP Factor Statement Design.

The CPP questionnaire was administered after each of the data collection scenarios (A, B, C). Immediately after the scenario was over, the subject reviewed a videotape of the CPP and complete the questionnaire. Again, each subject performed three scenarios that contained a CPP and one baseline Standard scenario that was a routine arrival without any unusual circumstances.

Experimental Design

This experiment measured the response of the subjects to each of the statements included in the CPP questionnaire. This value was the primary dependent variable upon which an analysis of variance was later applied to determine the extent to which the prioritization factors were used to prioritize tasks during the scenarios. Following is a detailed description of the mixed factor design of the experiment.

Dependent Variable:

Prioritization Factor Score

Agreement/disagreement with the use of a prioritization factor in determining the order that tasks were performed at a CPP.

Independent Variables:

Prioritization Factor

A fixed effect variable with 6 levels ***(status, procedure, value, urgency, salience, time/effort).***

Task Category

A fixed effect variable with 4 levels ***(aviate, navigate, communicate, manage systems)***.

Scenario

A fixed effect variable with 3 levels ***(scenario-A, scenario-B, scenario-C)***.

Subject

A random effect variable with 8 levels ***(subjects 1-8)***.

In addition to the above analysis, two other analyses were performed. First, the order that subjects performed each task in the CPPs was analyzed to examine any trends that might be insightful as to the use of the prioritization factors.

Finally, the actual performance data from the simulator was analyzed to distinguish the good from the poor performers.

Simulator tasks

The tasks performed in the part-task simulator were consistent with the previous experiment (see Chapter 4.)

Navigational equipment was limited to a single very-high-frequency omnirange (VOR) navigation instrument for this study (see Glossary in Appendix 1 for definitions of aircraft instrumentation). While this is a very minimal configuration, it was ample for the scenarios and is an accurate partial representation of true navigational tasks. VOR displays and controls consisted of the navigational display, which included a VOR deviation indicator, distance measuring equipment (DME) distance from the ground-based VOR, course setting and VOR frequency. The VOR frequency control was located on the radio displays, and the VOR radial input selector was located on the mode control panel (see Figure 5.5).

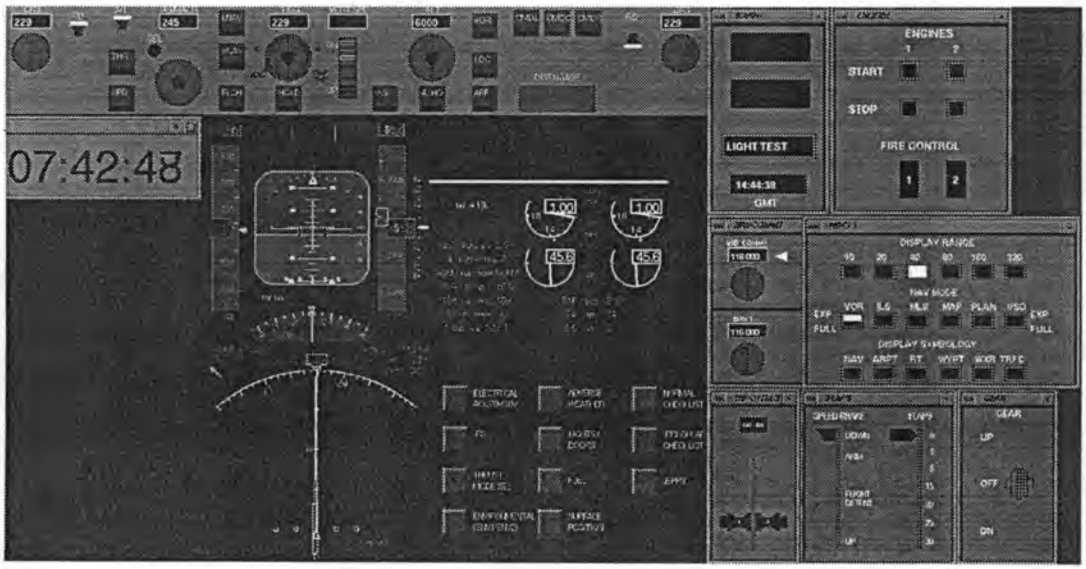


Figure 5.5 Stone Soup Simulator Screen Shot.

Communications between the pilot and simulated ATC was perform in a direct verbal exchange, as the pilot and experimenter were within approximately 5 feet of each other. Verbal exchanges were restricted to standardized radio procedures and there was no free conversation between pilot and experimenter during data collection scenarios. As a small added communications task, the pilot was required to dial in the proper communications radio frequency before an exchange with ATC.

Other system management tasks were performed in the simulator through various controls and displays. For example, equipment malfunctions illuminated the caution indicator and display a message in the Engine Indication and Crew Altering System (EICAS) display area. The equipment malfunctions could then be acknowledged and reset by performing a series of mouse click inputs to the multifunction display/control panel of the simulator.

A task analysis for this study was simplified and refined from the analyses performed by Alter, K.W., and Regal, D.M. (1992) and McGuire, J.C., et al. (1990). This resulted in the identification of the tasks listed in the pilot questionnaire. This was consistent with the ANCS task taxonomy accepted in both the pilot and aviation research communities.

Procedure

Pilots arrived for the 5-hour experiment and immediately completed an informed consent document (Appendix 6) and pre-trial questionnaire (Appendix 7) to record flight experience, age and to ensure no extenuating circumstances interfered with the trial, such as excessive caffeine or lack of sleep the night before.

Pilots were then given a brief overview of the experiment. They were notified that their flying performance was being measured in this experiment and that comments made to the experimenter would be separated from their names and would be kept confidential. The sequence of the experiment consisted of approximately 3 hours of training on the simulator, followed by a break, then an additional 30-minute training session. Finally, the four data-collection scenarios were flown on the simulator.

The training consisted of a very structured, consistent presentation of the tasks needed to fly the simulator. Appendix 8 is the syllabus used for training and was adapted from the NASA Aircraft Operations Manual for the Advanced Concepts Flight Station, which is part of the Stone Soup Simulator documentation.

After training, a general description of the data collection procedure was presented, explaining how the interviewing technique was administered. The data collection scenarios would then begin. Once again, the order of the scenarios was determined by a Latin square design, as outlined above.

After the pilot had completed the last data collection scenario, he was immediately given a post-test questionnaire, inquiring about how comfortable the pilot was with flying the scenario and if the training was adequate for testing purposes. Additionally, the pilot was encouraged to discuss his thoughts and feelings about anything related to the experiment. This completed the experiment.

Results

The data collected in this study contained several dimensions and lent itself to several different analyses. The analyses presented below are all directed at the subjects' use of the proposed factors that affect task prioritization.

Primary ANOVA

Challenge Probe Point Questionnaire

Each of the statements in the Challenge Probe Point (CPP) questionnaires (Appendix 5) were scored accordingly:

Subject Response	Resulting Score
Strongly Agree	+2
Agree	+1
N/A	0
Disagree	-1
Strongly Disagree	-2

These scores were then tallied for each of the 6 prioritization factors and 9 tasks (3 tasks from each of the 3 scenarios). Table 5.2 presents the sum total and average for each of the 54 task-factor combinations, the sum total and average for the 18 CPP-factor combinations and finally the sum total and average for the 6 overall prioritization factors.

CPP-A Tasks		Status	Procedure	Value	Urgency	Salience	Time/Effort
Navigate: InitiateTurn	Sum	-5	8	7	4	-3	0
	Average	-0.63	1.00	0.88	0.50	-0.38	0.00
Communicate: Respond to ATC	Sum	-7	7	-10	-6	6	3
	Average	-0.88	0.88	-1.25	-0.75	0.75	0.38
Manage Systems: Perform Engine Fire Checklist	Sum	6	7	14	8	5	-3
	Average	0.75	0.88	1.75	1.00	0.63	-0.38
CPP-A Total	Sum	-6	22	11	6	8	0
	Average	-0.25	0.92	0.46	0.25	0.33	0.00

CPP-B Tasks		Status	Procedure	Value	Urgency	Salience	Time/Effort
Navigate: Track Localizer and G/S	Sum	-6	14	12	-3	1	2
	Average	-0.75	1.75	1.50	-0.38	0.13	0.25
Communicate: Report FAF to ATC	Sum	-5	9	-4	-6	0	4
	Average	-0.63	1.13	-0.50	-0.75	0.00	0.50
Manage Systems: Perform Bus Tie Contactor Checklist	Sum	0	4	3	2	8	1
	Average	0.00	0.50	0.38	0.25	1.00	0.13
CPP-B Total	Sum	-11	27	11	-7	9	7
	Average	-0.46	1.13	0.46	-0.29	0.38	0.29

CPP-C Tasks		Status	Procedure	Value	Urgency	Salience	Time/Effort
Aviate: Stop descent for traffic	Sum	-4	9	11	5	11	-2
	Average	-0.50	1.13	1.38	0.63	1.38	-0.25
Navigate: Intercept the Localizer	Sum	-3	6	5	7	8	0
	Average	-0.38	0.75	0.63	0.88	1.00	0.00
Manage Systems: Attend to Master Warning Light	Sum	-2	-6	0	-7	8	-1
	Average	-0.25	-0.75	0.00	-0.88	1.00	-0.13
CPP-C Total	Sum	-9	9	16	5	27	-3
	Average	-0.38	0.38	0.67	0.21	1.13	-0.13

Oveall Total	Sum	-26	58	38	4	44	4
	Average	-0.465	0.927	0.348	-0.156	0.507	0.162

Table 5.2 Sum and Average Results

The data in Table 5.2 were the resulting scores of the Likert-type questionnaire developed for the CPPs. It is common to perform an analysis of variance statistical analysis of Likert-type data as long as the assumption is met that each statement is unidimensional (Graham and Lilly, 1984). In other words, the statement should measure only one subjective opinion and not two or more. In the case of the CPP statements, this assumption held true, as the dimension being measured was the pilots' agreement or disagreement with his use of each factor in determining the order in which to perform the CPP tasks. The analyses presented below were performed using the Statgraphics Plus for Windows 3.0 software program from Statistical Graphics Corporation.

Scenario

The scenario, with three levels (A, B, C) was evaluated using analysis of variance and was found to have an insignificant effect. This establishes that subjects' use of the prioritization factors were independent of the scenario. Therefore, the scenario factor was removed from the model, resulting in a 3 factor mixed effect model.

Prioritization Factors

The CPP questionnaire values were analyzed using ANOVA. Recall from the experimental design that this is a fixed effect factor having six levels (status, procedure, value, urgency, salience, time/effort). These factors were found to be a significant effect ($F(5,35) = 5.14$, $p < .01$). As can be seen in Figure 5.6, over the entire experiment, ***procedure*** emerged as the factor most agreed to by pilots for use in task prioritization, followed in descending order by ***salience, value, time/effort, urgency*** and finally ***status***.

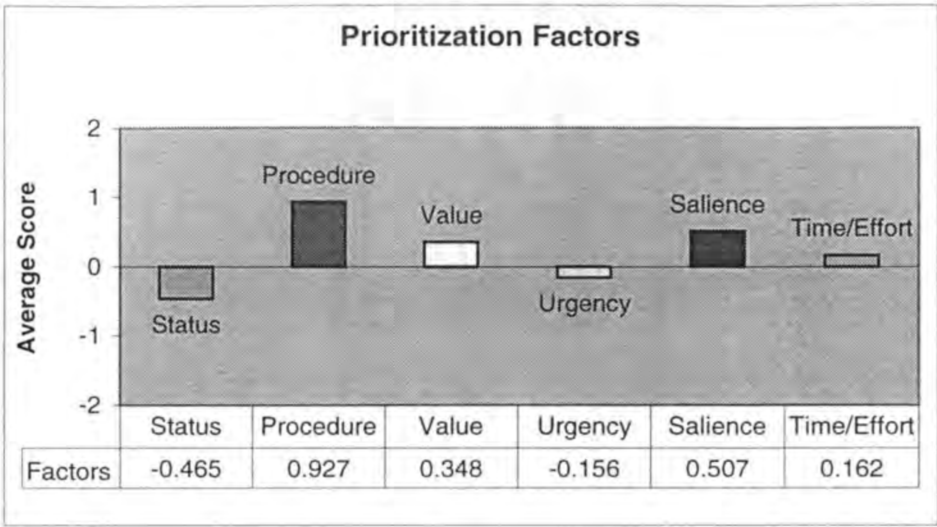


Figure 5.6 Prioritization Factors.

As depicted in Figure 5.6, a positive value represented supporting evidence that pilots used the factor in determining the priority of a particular task. The corresponding magnitude of the value represented the agreement with the factor, using the (–2, -1, 0, +1, +2) scale developed for the CPP questionnaires. The maximum value a specific factor could be in this analysis is a +2 (strongly agree) score. Similarly, a negative value corresponded to the subject reporting disagreement with using a particular prioritization factor (e.g., the ***status*** factor in Figure 5.6).

Task Categories

Each of the nine tasks probed in the CPP questionnaires were categorized into the ANCS classification (see Table 5.1). This effect was found to be significant ($F(3,21) = 6.09$, $p < .01$). As can be seen in Figure 5.7, the prioritization factors were most agreed upon by the subjects when performing the aviate tasks. The other tasks, in descending order, are manage systems, navigate, and finally communicate. Factors with a negative score (i.e., the communicate tasks in Figure 5.7) indicate subjects disagree with using the prioritization factors on these tasks.

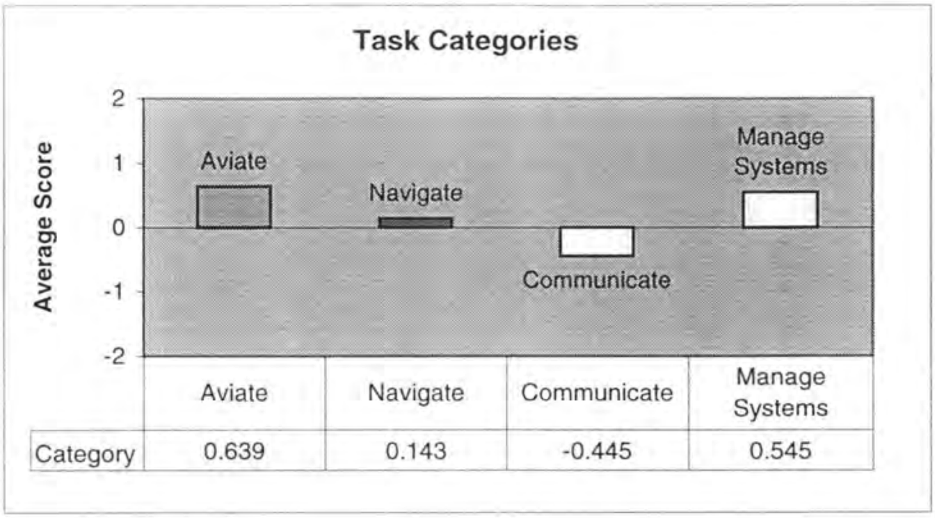
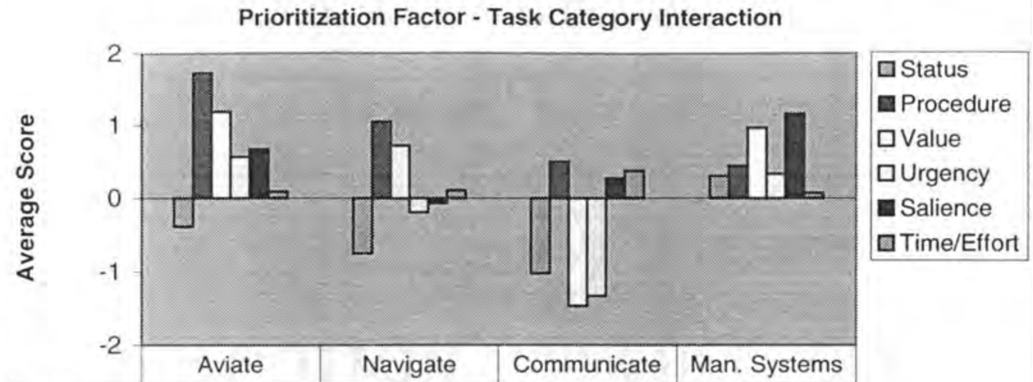


Figure 5.7 Task Categories.

Prioritization Factor – Task Category Interaction

The prioritization factor-task category interaction was found to be highly significant ($F(15,105) = 4.32$, $p < .001$). As can be seen in Figure 5.8, this finding establishes that the subjects' agreement with the use of the prioritization factors depends on which task is being evaluated for execution. In general, the aviate and manage systems tasks show strong agreement, while the communicate tasks show strong disagreement in the ***status***, ***value*** and ***urgency*** factors. The navigate tasks show mixed results.



	Aviate	Navigate	Communicate	Man. Systems
Status	-0.393	-0.749	-1.021	0.304
Procedure	1.720	1.047	0.497	0.443
Value	1.182	0.715	-1.465	0.960
Urgency	0.561	-0.191	-1.327	0.332
Salience	0.670	-0.073	0.273	1.157
Time/Effort	0.091	0.107	0.376	0.075

Figure 5.8 Factor – Category Interaction.

Subjects

The subjects' effect on the resulting CPP questionnaire scores were also found to be highly significant ($F(7,240) = 4.53$, $p < .001$). As can be seen in Figure 5.9, four subjects reported an overall average agreement with the prioritization factors, while four reported an overall average disagreement. Subject 7 reported the highest agreement, while subject 5 reported the lowest overall score. This result indicates that there is little overall consistency between subjects in their agreement with the use of the factors that affect task prioritization.

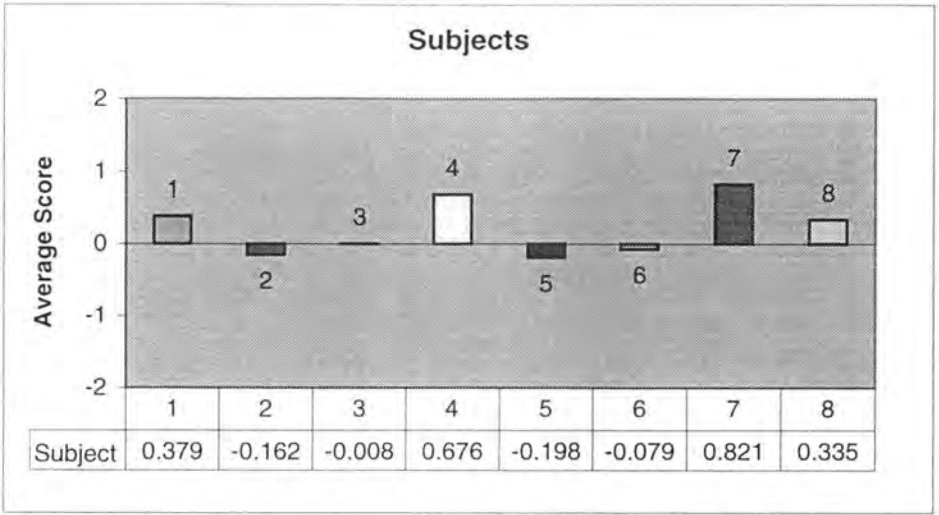
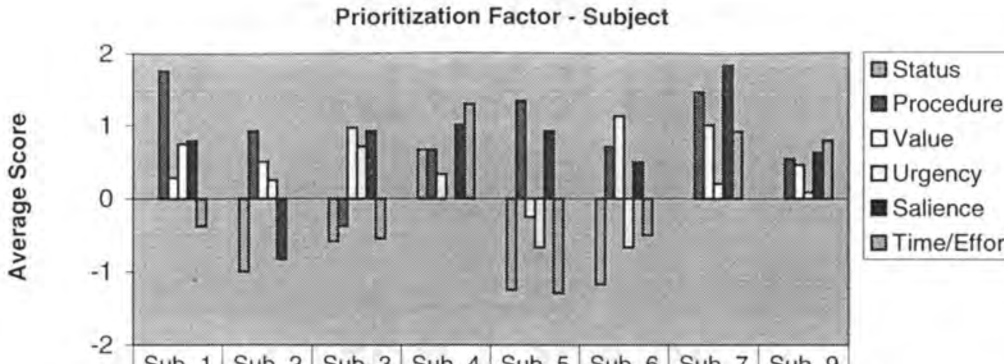


Figure 5.9 Subjects.

Multiple range tests were performed to determine significance differences in the response of the individual subjects. Application of Fisher's least significant difference procedure at the 99% level resulted in the identification of 4 homogeneous groups within the 8 subjects.

Subject - Prioritization Factor Interaction

The subject - prioritization factor interaction was found to be significant ($F(35,240) = 1.93$, $p < .01$). As can be seen in Figure 5.10, the agreement with particular prioritization factor is highly dependent upon the subject. In other words, subjects show little consistency in their agreement with the use of prioritization factors.



	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Sub. 7	Sub. 9
Status	0.000	-1.000	-0.583	0.667	-1.250	-1.167	0.000	0.000
Procedure	1.750	0.917	-0.375	0.667	1.333	0.708	1.458	0.542
Value	0.292	0.500	0.958	0.333	-0.250	1.125	1.000	0.458
Urgency	0.750	0.250	0.708	0.000	-0.667	-0.667	0.208	0.083
Salience	0.792	-0.833	0.917	1.000	0.917	0.500	1.833	0.625
Time/Effort	-0.375	0.000	-0.542	1.292	-1.292	-0.500	0.917	0.792

Figure 5.10 Subject – Prioritization Factor Interaction.

Task Execution Order Analysis

The task execution order at each CPP was analyzed by adding the order in which each task was performed to the data set collected above for the initial analysis of variance. The effect of order was found to be significant ($F(5,315) = 2.96$, $p < .02$). Interestingly, as can be seen in Figure 5.11, subjects appear to agree with the use of the prioritization factors most for the task that is performed third. However, a Fisher's least significant difference test at the 99% level fail to establish a statistical difference between the tasks performed in the first through fifth positions.

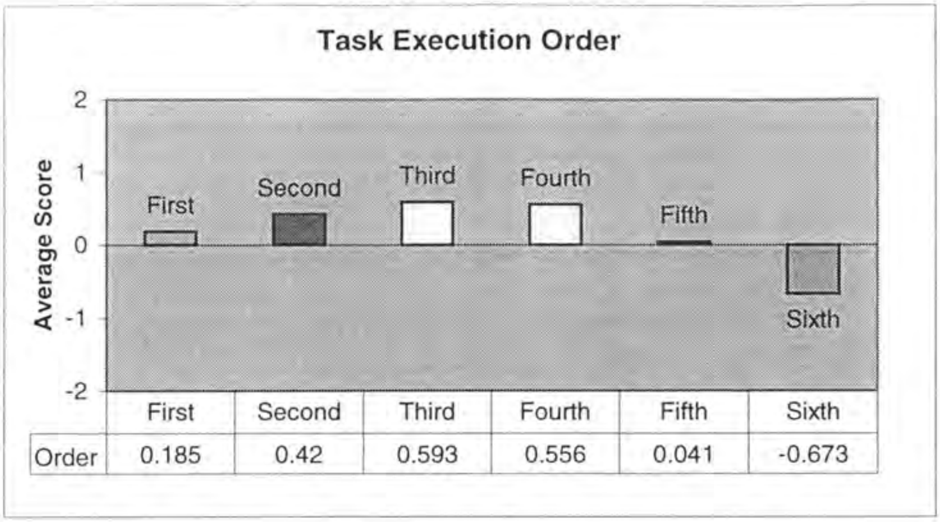


Figure 5.11 Task Execution Order.

Actual Task Prioritization vs. Revised Task Prioritization

Recall from Chapter 3, an assumption made for the present research was that the order that the tasks are performed in is approximately equivalent to the priority assigned to the tasks by the subjects. Therefore, a second dimension of the data collected in the present experiment was related to the order in which the tasks were performed at each of the CPPs. Again, a CPP is an operational situation in the scenarios where up to 6 tasks become active at the same instant. The pilot must decide the order in which the tasks are performed.

The initial part of the CPP questionnaire (Appendix 5) required the subjects to record the order that they performed the multiple tasks. Table 5.3 presents the actual task execution order for each of the 8 subjects performing in each of the 3 scenarios. This was accomplished with a review of videotape of the CPP. The subjects were allowed to replay the video as many times as was necessary to accurately record the order that the tasks were performed.

CPP-A Tasks	S1	S2	S3	S4	S5	S6	S7	S8
Engine Fire Checklist	5	3	1	2	5	3	2	1
Respond to ATC	3	2	3	1	3	1	1	2
Turn to heading 240	2	4	4	3	1	2	3	3
Initiate descent	1	5	5	4	2	4	4	4
Reduce speed	4	1	2	5	4	5	5	5
Configure panel for ILS	6	6	6	6	6	6	6	6
CPP-B Tasks								
Track the ILS	3	1	1	1	1	2	2	1
Low fuel checklist	DNP	5	DNP	2	DNP	3	1	DNP
Report FAF to tower	1	2	4	4	2	1	3	3
bus tie contactor checklist	2	3	2	DNP	DNP	4	4	DNP
final approach checklist	4	6	3	3	3	6	6	2
270V DC circuit breaker checklist	DNP	4	5	DNP	DNP	5	5	DNP
CPP-C Tasks								
Stop descent	1	1	1	1	1	1	1	1
Attend to master warning lights	5	5	5	4	4	DNP	DNP	4
Respond to ATC	3	3	2	2	2	2	4	2
monitor/reduce airspeed	4	4	4	5	5	4	2	DNP
turn onto localizer	2	2	3	3	3	3	3	3

Table 5.3. Actual Task Execution Order. (DNP – Did Not Perform Task).

In CPP-A, only two subjects, 4 and 7 performed the tasks in exactly the same order. Subjects 6 and 8 were very similar, differing in the order of just 2 tasks from the order selected by subjects 4 and 7. In CPP-B, no two subjects performed the tasks in the same order. However, in CPP-C, there was more consistency. Subjects 1 and 2 performed the tasks identically, with all subjects performing the stop descent task first and there was much more consistency in the remaining tasks than observed in the other two CPPs.

Additionally, the last part of the CPP questionnaire gave the pilots an opportunity to evaluate the order that they performed the multiple tasks. There was no feedback from the experimenter regarding performance during the CPP. However, the subjects had just completed an evaluation of the 18 statements related to the prioritization factors, so they had carefully thought about their justification of why they performed the tasks in the order that they did. If the subjects, in retrospect, revised the order that they performed the tasks, then the revised order is presented in Table 5.4. Over the course of the experiment, which included 24

CPPs, 13 times, or 54% of the time, pilots would have performed the tasks in a different order. An analysis of variance on the effect of the subject's decision to change the execution order resulted in no significant effect on the subject's responses to the factor statements in the CPP questionnaires.

CPP-A Tasks	S1	S2	S3	S4	S5	S6	S7	S8
Engine Fire Checklist	3	4	1	same	same	2	1	1
Respond to ATC	4	1	5	same	same	4	2	5
Turn to heading 240	1	2	3	same	same	1	3	2
Initiate descent	2	3	2	same	same	3	5	3
Reduce speed	6	5	4	same	same	5	4	4
Configure panel for ILS	5	6	6	same	same	6	6	6
CPP-B Tasks								
Track the ILS	2	same	same	4	1	1	same	same
Low fuel checklist	WNP	same	same	2	3	WNP	same	same
Report FAF to tower	1	same	same	5	2	2	same	same
bus tie contactor checklist	3	same	same	1	WNP	4	same	same
final approach checklist	4	same	same	3	4	3	same	same
270V DC circuit breaker checklist	WNP	same	same	6	WNP	5	same	same
CPP-C Tasks								
Stop descent	1	same	same	same	2	same	same	1
Attend to master warning lights	5	same	same	same	4	same	same	WNP
Respond to ATC	3	same	same	same	3	same	same	4
monitor/reduce airspeed	4	same	same	same	5	same	same	3
turn onto localizer	2	same	same	same	1	same	same	2

Table 5.4 Revised Task Execution Order. (WNP – In retorspect, would not perform the task. Same – Would not change order the tasks performed).

Task Performance Analysis

The performance data collected from the flight simulator was analyzed for errors. In the present study, a performance error was committed only under very well defined and extreme conditions (see Appendix 9). As an example, when ATC issues an altitude clearance, FAA regulations stipulate that a tolerance of +/- 100 feet from the assigned altitude is an allowable deviation. To constitute an altitude deviation error in this study, the subjects had to deviate from the assigned altitude by more than +/- 200 feet. Pilots were fully aware of these error conditions primarily through their familiarity with the Federal Aviation Regulations (FARs). Other aircraft-specific error conditions were explicitly explained to them during the training portion of the experiment.

Over the course of the entire experiment, 7 subjects committed 9 performance errors in the 24 scenarios flown (Table 5.5). Figure 5.12 depicts the average score when an error is committed, while Figure 5.13 is the score when no error is found. An analysis of variance of this data found no significant differences between the error and non-error conditions on the subject's responses to the factor statements in the CPP questionnaires.

Subject	Scenario	Error
1	A	Altitude Error: Crossed SUNOL waypoint 282' low
	B	Fail to Perform Fuel Crossfeed Task.
	C	Altitude Error: Altitude deviated more than +300' and -300' to assigned altitude
3	B	Fail to Perform Fuel Crossfeed Task.
4	A	Altitude Error: Deviated more than 300' from assigned altitude. Desent Rate Error: Descended at more than 2300'/min.
5	B	Fail to Perform Fuel Crossfeed Task.
6	C	Altitude Error: Deviated 200' from assigned altitude
7	A	Altitude Error: Crossed SUNOL waypoint 500' high
8	B	Fail to Perform Fuel Crossfeed Task.

Table 5.5 Task Performance Errors.

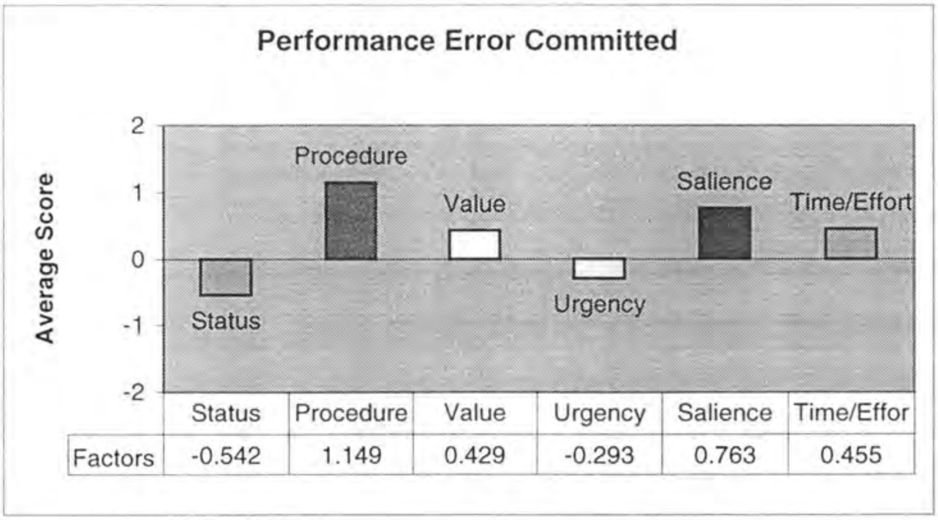


Figure 5.12 Average Score When Error is Committed.

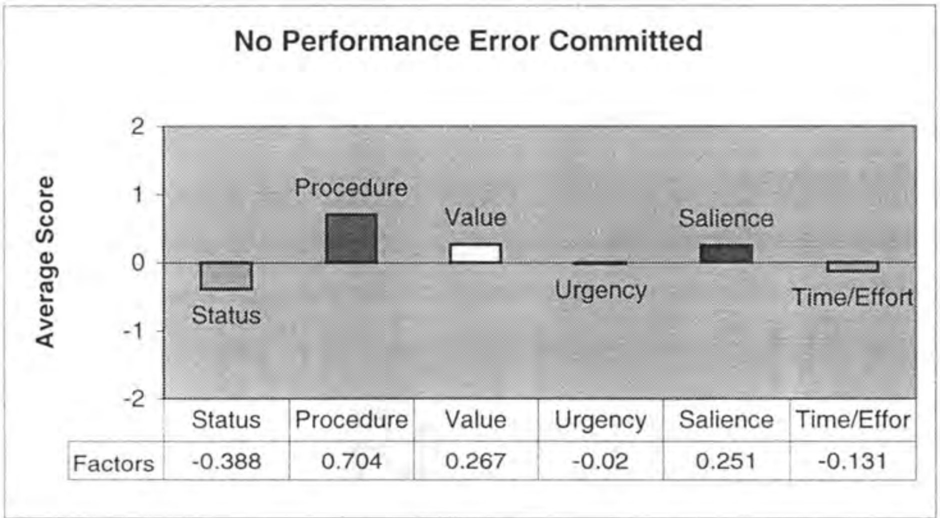


Figure 5.13 Average Score When Error is Not Committed.

Discussion

Individual Differences

One of the primary findings in this study was the individual differences pilots exhibited in the task prioritization process. This is consistent with the findings of Schutte and Trujillo (1996), in which they concluded CTM was largely dependent on individual differences between flight crews and personal style. While this study considered only single pilot operations, both the statistical significance of the effect of subjects on the questionnaire scores and the corresponding graphical depiction in Figure 5.10, it is apparent that there is no general prioritization vector for pilots as a whole, as suggested by others (e.g., Gopher, 1992; Logan, 1985; Adams and Pew, 1990).

However, this is not to say that prioritization vector is a poor conceptual approach to a representation of the task prioritization process. Since there is truly no single, optimal task execution order in the majority of situations on the flight deck, there may not be a single optimal task prioritization vector. Rather than a prioritization vector that is applicable to pilots in general, it may be more useful to be able to establish several prioritization vectors that all result in equally-optimal task performance. Following, then, a pilot's individual prioritization vector could be compared to established prioritization vectors.

Another concept in support of the individual differences found in this study was the realization that each pilot has a unique knowledge base, which was used to apply these prioritization factors. The pilots in this study had amazingly different training and experiences, ranging from military pilots, to Alaskan bush pilots, to flying instructors. The expectation that individuals with such diverse experiences all have similar knowledge representations and apply prioritization factors in a consistent manner may be unrealistic.

In the present experiment, subject 1 had the distinction of being the worst performing pilot by committing a performance error at each of the 3 CPPs. The prioritization vector for subject 1 is given in Figure 5.14. The statistical analysis (multiple range tests) of this vector was unable to distinguish a difference between it and the vectors from subjects 4, 7 and 8. Interestingly, subjects 4, 7 and 8 each committed an error in one of the three CPPs with which they were presented.

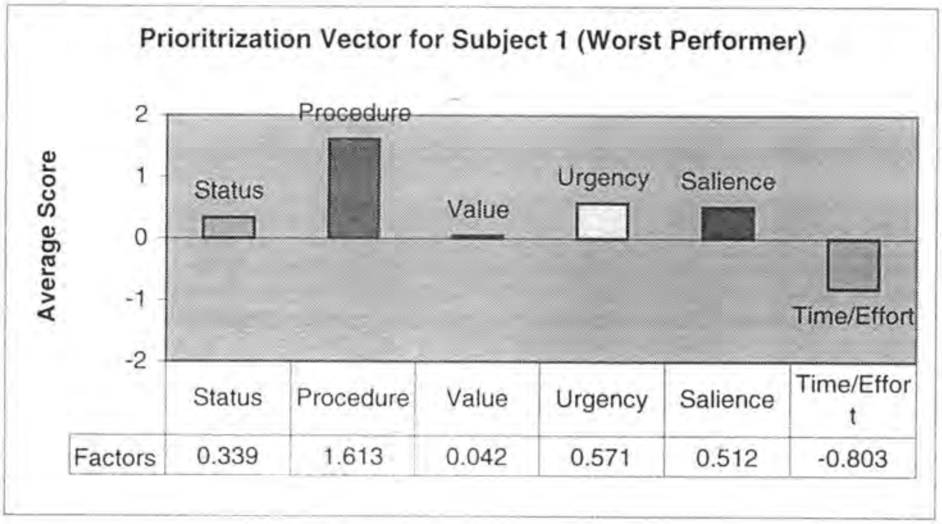
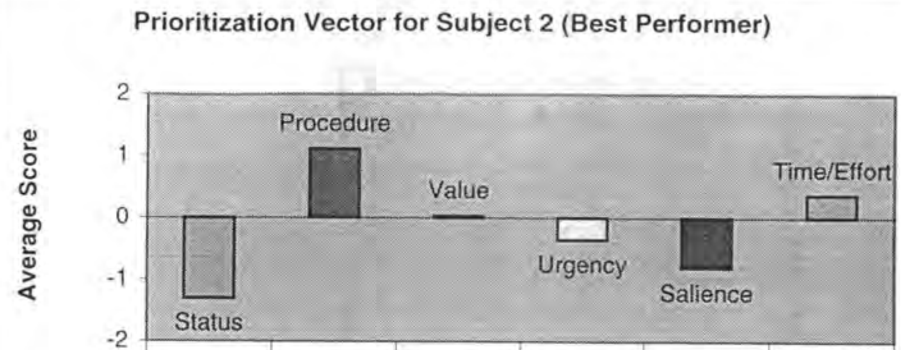


Figure 5.14 Task Prioritization Vector for Subject 1.

Subject 2 was the best performing pilot by being the only subject to not commit a single error in any of the CPPs. The prioritization vector for subject 2 is given in Figure 5.15. Again, a multiple range test was unable to establish a statistical difference in the prioritization vectors between subject 2 and subjects 3, 5 and 6. Again, these subjects (3, 5 and 6) committed an error in one of the three CPPs.



	Status	Procedure	Value	Urgency	Salience	Time/Effort
Factors	-1.31	1.112	0.026	-0.359	-0.813	0.369

Figure 5.15 Task Prioritization Vector for Subject 2.

With the limited number of data points in this study, it is not possible to establish the envisioned prioritization vector categories, but this may be a direction to pursue. It is methodologically reassuring that subject 1 (worst performer) and subject 2 (best performer) did not have statistically equivalent prioritization vectors.

ANCS Prioritization Hierarchy

The conceptual basis of the ANCS task hierarchy is that tasks have inherent priorities that are independent of the current context. In other words, aviate tasks always have a higher priority than navigate tasks, which have a higher priority than communicate tasks, and so on. However, it is not difficult to conceptualize situations in which this prioritization scheme breaks down and the tasks take on a priority inconsistent with the ANCS hierarchy. For example, it may be necessary to perform a manage systems task, such as balancing fuel loads in wing tanks, before the aircraft is maneuverable enough to aviate. In such a situation, the ANCS gives an invalid prioritization strategy.

However, the findings in the current study do reflect some of the characteristics of the ANCS prioritization scheme. For example, the aviate tasks do exhibit the most agreement from pilots in the use of the prioritization factors. Subjects responded with the justification of "fly the airplane first" in both the comments section of the CPP questionnaire and informal discussion after data collection was over.

There are two aspects of the results, however, that appear to contradict the ANCS hierarchy. First, the communicate tasks show an overall negative agreement score (Figure 5.9). Further, it is only the ***status***, ***value*** and ***urgency*** factors that actually have negative scores (Figure 5.8). With respect to ***value*** and ***urgency***, pilots often lowered the priority of the communicate task when they were given the opportunity to change the order in which the performed the tasks. The pilots know that both the ***value*** and ***urgency*** of communicate tasks are relatively low, yet for some reason they tended to perform these tasks earlier than they thought was appropriate. With respect to the ***status*** factor, see the following section.

Second, pilots performing the manage systems tasks appeared to utilize the prioritization factors more than might be expected. This may be explained by inadequacy of the general ANCS approach. There are many tasks on the flight deck that do not fit nicely into the ANCS hierarchy. For example, a non-normal situation, such as an engine fire, is difficult to place at a lower priority than the navigate and communicate tasks. In fact, the results indicate that pilots do not adhere to such a strict prioritization scheme. In the present experiment, many of the manage systems tasks were of a non-normal nature and the pilots prioritized accordingly.

Accuracy of the Prioritization Factors

One major inconsistency in the results was the overall negative scores of the ***status*** prioritization factor. This is especially disconcerting considering ***status*** was the most reported factor in the initial study of prioritization factors (Chapter 4). It was anticipated that ***status*** would have been an often-used factor by the subjects.

That the ***status*** factor was resulting in disagreement by the subjects was apparent early on in the data collection. Rather than stop the experiment after a few subjects, it was decided to continue data collection, but to add some informal questioning of each subject after the experimental trial was over.

It was discovered that the particular wording of the CPP statements regarding the status prioritization variable was inappropriate for some of the tasks. This is best explained with an example. The statement regarding the ***status*** of the manage system task, engine fire checklist, in CPP-A (Appendix 5, statement A3-1) appeared as:

> *I performed the engine fire checklist when I did was because I judged it to be the task farthest from satisfactory completion. (A3-1)*

For the subjects, this was a statement consistent with the nature of the engine fire checklist task (i.e., it made sense to the pilots) and the results for the score of this task were, in fact, positive (Figure 5.8, ***status*** factor in the manage systems task category)..

However, when a similar statement was posed to the subjects regarding an aviate or navigate task, the fact that these tasks are not thought of as ever being "complete" in the context of a flight may have affected the resulting responses by the subjects. For example, a navigate task in CPP-B was to track the Instrument Landing System (ILS) instruments. The statement regarding the ***status*** of this task was as follows (Appendix 5, statement B1-1):

> *The reason I tracked the ILS when I did was because I judged it to be the task farthest from satisfactory completion. (B1-1)*

To the subjects, this was not an appropriate way to phrase this statement regarding the ***status*** of the task. Completion of this task occurs only at landing and it was not the intention of the statement to assess the subject's evaluation of the task as related to landing the aircraft. Rather, it was the intention to evaluate the deviation from the localizer and glide slop indicators the aircraft was at that particular instant. This statement failed in the accurate assessment of this task and, in retrospect, other tasks in the experiment.

The solution to this situation was, in hindsight, rather simple. If the statement had been worded slightly differently, to reflect the context of each category of task, it is anticipated that the use of the status factor would have shown a much higher score. For example, the rewording of the B1-1 statement could have been as follows:

> *The reason I tracked the ILS when I did was because I judged it to be the task farthest from a satisfactory performance level.*

The informal feedback from the subjects, after data collection was complete, did not explicitly identify other obvious errors in the wording of the CPP statements. Therefore, it is assumed that the other statements resulted in satisfactory responses from the pilots regarding other task-factor combinations.

The Prioritization Vectors Fitted to Preliminary Task Prioritization Model

Recall that the 6 prioritization factors investigated in the present study were a subset of 12 factors identified in Chapter 4. They were selected by the frequency with which they were reported in the initial identification of the factors that affect task prioritization. By again fitting the 6 factors back into the 3 primary prioritization factors of Figure 4.8, the extent to which pilots agree that they used the 3 primary factors of task prioritization can be seen in Figure 5.16. In other words, three factors investigated in the current study, ***status***, ***salience*** and ***urgency*** are all included in the primary factor ***status*** from Figure 4.8. Similarly, ***time/effort*** and ***procedure*** are included in the primary ***procedure*** factor. The ***value*** factor stands alone and does not include multiple factors from the earlier study.

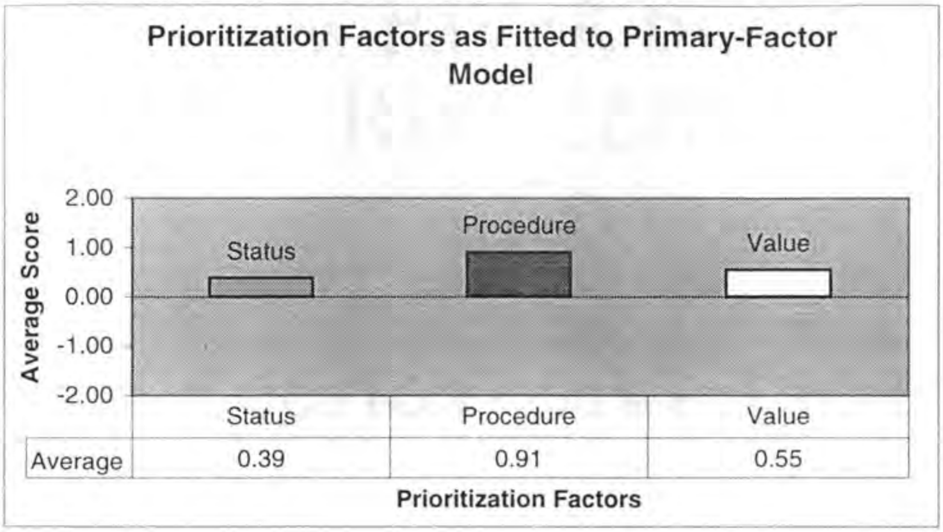


Figure 5.16 Prioritization Factors Fitted to the Preliminary Task Prioritization Model.

With these results, it appears that overall ***procedure*** is the most influential factor that affects task prioritization. This is not entirely surprising, as piloting of aircraft is highly procedural and the current training programs reflect this in their highly procedure-based philosophies.

The effect of ***value*** was found to have more influence in task prioritization than was initially established in the previous study (Chapter 4). This is reassuring, as the one satisfactory order to perform the tasks would be to always perform the most important tasks to a level of satisfactory status before attending to other, less important tasks. Finally, the ***status*** factor did show limited effect in the model, but it is believed to have a bigger effect, as discussed in the previous section.

Limitations

Current resource limitations enabled the current study to only look at single pilot behaviors in a part-task simulator. Since all of the subjects that participated in this study were current commercial transport pilots, their true operational environment was on a 2 pilot flight deck. It would have been much more ecologically valid to study 2 pilot crews. However, it is anticipated that this would have greatly reduced the workload experienced by the pilots in the CPPs, thus reducing the need for the pilot to prioritize 6 concurrent tasks. Therefore, in the current study of prioritization factors, the high workload situations created were conducive for the objectives of the research.

Although extensive training on the simulator was incorporated into the current experiment, it was still a very different operational context from the actual aircraft the subjects fly on a day to day basis. There are two directions future studies could take regarding this limitation. On the one hand, experimentation could be directed towards a full-motion, high fidelity simulator. This would provide an environment as close to the actual environment as possible, without actually flying in the aircraft. Current high fidelity simulators would provide an excellent research tool, as they are able to capture a wide range of performance statistics that could be used to accurately evaluate pilot performance. However, there are many obstacles to overcome, such as access to such a simulator and the prohibitive costs.

An alternative approach would be to not attempt to increase simulator fidelity, but rather to abstract task characteristics. Computer graphical simulation tools are available to create multiple displays, which could represent multiple concurrent tasks, with remote similarities to flying tasks, but perhaps more generalized to allow non pilots to participate in the experiments. It would be interesting to study factors that affect task prioritization for groups of humans other than highly trained commercial pilots. This approach might diminish the affect of a pilot's knowledge base, as discussed above, and investigate what might be considered a more general prioritization vector.

Conclusions

The present study started with the conceptualization of the task prioritization process as a vector of factors and attempted to investigate those factors. A primary conclusion is that no general prioritization vector was found in the data. However, it may be that categories of prioritization vectors could be established. Pilot prioritization schemes could then be evaluated according to these categories. The prioritization vector approach may be an interesting research area to pursue.

It is very apparent that even highly trained and skilled humans do not always perform task prioritization optimally when presented with multiple, competing tasks. Pilots, when given the opportunity to (retrospectively) order tasks in a different sequence, chose to do so in more than 50% of the CPPs. This finding is consistent with findings in other domains (Moray, et al., 1991).

The ANCS hierarchy does not hold up rigidly in all circumstances. Subjects often performed communicate tasks much earlier than they should have, and acknowledged this when they reprioritized the tasks in retrospect.

The primary contribution the present work has made is the investigation of factors that affect task prioritization on the flight deck. This is by no means a completed task; it is just the beginning. While the present work has utilized and developed some creative methods for studying prioritization factors, there is a need for better, more robust and reliable methods.

CHAPTER 6:
CONCLUSIONS

The present research has covered a lot of ground. It began with a review of the existing work performed in CTM over the past decade. Most of these early works approached CTM from a systems perspective, treating the prioritization of tasks as an explicit, rational process. Several theories were presented, each adding new insight and understanding to a complex cognitive function. Attempts at aiding human task management performance were investigated using CTM facilitation systems, some showing considerable performance improvements in the management of tasks.

In an attempt to expand and refine the theoretical dimensions of CTM, a human performance approach was investigated. From these efforts, three specific areas were found to have significant relationships to CTM. These three areas, task automaticity, voluntary control of attention and time-sharing abilities, all pointed toward a single, unanswered research question: What are the factors that affect task prioritization?

In an attempt to address this question, two flight simulator studies were performed using highly skilled commercial airline pilots. The first study was a hypothesis-generation study, attempting to capture possible prioritization factor candidates. The second study further investigated empirical support for those factors.

In order to move beyond the obvious interpretations of the experimental results, the next section attempts to extract the key points discovered in the current research effort and integrate these findings into the existing CTM theory.

Theoretical Constructs Drawn from the Current Research

The current section analyzes the overall findings of the present research effort and identifies theoretical constructs relevant to CTM. Alone, these theoretical constructs comprise an incomplete theory of the CTM process.

However when combined with previous works, it is a move towards a better understanding of CTM, the flight deck task environment, task prioritization and humans' abilities to manage and perform multiple, concurrent tasks.

The theoretical constructs of CTM are categorized into four topics: (PF) the prioritization factors investigated; (P) the people involved in the task environment; (T) the task itself; and (TE) the task environment where multiple, concurrent tasks are performed.

Prioritization Factors

The primary objective of the current research was to identify and investigate the factors that affect task prioritization on the flight deck. The initial experimental study (Chapter 4) used creative knowledge elicitation techniques to identify 12 factors, which were condensed into a 3 primary-factor model comprised of ***Status***, ***Procedure*** and ***Value*** (Figure 4.8). The second experimental study (Chapter 5) collected data with the intent of developing a vector of task prioritization. While the evidence suggests that there is no single prioritization vector, there are subtle patterns and consistencies that suggest prioritization vector categories may exist. It is not known why these categories appear and is left as a topic for future research.

While the current project has identified 3 primary prioritization factors and 12 specific factors, it is suggested that others may exist. For example, ***task momentum***, defined as the tendency to continue the task currently being performed, did not appear in any of the data collection points in either of the experiments. It is anticipated that prioritization factors such as this do, in fact, exist, but the current methods were unable to identify them. Again, these challenges are left as the objectives of further research.

Theoretical Constructs about PRIORITIZATION FACTORS:

PF1. Status, Procedure and Value are primary factors that affect task prioritization.

PF2. Other prioritization factors may exist, but were not identified in the present study.

People

The results from the second experimental study (Chapter 5) strongly indicate that people use different prioritization factors to determine the order in which tasks are performed. While it is unfortunate that a general prioritization factor does not exist like some have suggested (i.e., Gopher, 1992, Logan, 1985; Adams and Pew, 1990), there does appear some consistency between individuals, which might suggest prioritization factor categories. What specifically determines these categories, however, is not clear, and may be related to complex concepts like personality type (Gladwell, 1999), training techniques (Gopher, 1992) and the individual pilot's past flight experience.

Pilots often indicated that, in retrospect, they would have changed the order in which they performed tasks at the Challenge Probe Points (CPPs). This indicates prioritization in the "heat of the moment" is often not performed in the same way that it would be if the pilots were given the chance to carefully consider the individual tasks and the context of a challenging situation. While it is difficult or even impossible to determine the optimal prioritization of the tasks at the CPPs, the fact that so many pilots (54%) decided to change the task execution order is an indication that they are prone to execution order errors. One reason might be that people are just not optimal at ordering multiple, concurrent tasks, which is consistent with findings in other domains (e.g., Moray, et al., 1991). Another reason might be that pilots just do not know what the proper task execution order at a CPP should be. Further, there were many instances where pilots violated their well-accepted and commonly used ANCS prioritization strategy (i.e., reply to ATC (communicate) before initiating a descent or turn (navigate)). This indicates that although pilots might know how to properly prioritize tasks, when faced with the decision at a CPP, they fail to do so correctly.

Theoretical Constructs about PEOPLE:

P1. Pilots do not all prioritize multiple, concurrent tasks in the same way.

P2. Pilots would often change task execution order when given the chance to retrospectively evaluate a situation.

P3. Pilots are prone to prioritization errors in challenging situations.

Tasks

The present study was not primarily concerned about the performance of specific tasks, however, as established in Chapter 3, the automaticity of a task determines how much of the human's attentional resources are needed to perform it. In general, the more automated a task becomes, the less resources are required for the pilot to perform it. However, some tasks (i.e., communicate tasks) are just not good candidates for automatic behavior, and should be performed in a controlled processing mode. Therefore, pilots should be trained to automate many tasks allowing for a reduced attentional load, and freeing up resources for the demands of those tasks that are best performed in controlled processing mode.

The ANCS task classification hierarchy is commonly used by pilots and is a basis for their default prioritization strategy. While it provides a good fundamental approach, it has some shortcomings and pilots do not always strictly adhere to it. For example, it was often the case in the second experiment (Chapter 5) that pilots replied to an ATC clearance almost instantaneously, in spite of the fact that other higher priority tasks were in demand of the pilot's attention (i.e., initiate descent, initiate turn). Additionally, under a strict ANCS strategy, an engine fire checklist (manage systems task) would have a lower priority than the ATC response (communicate task). Obviously, in such a situation, the pilot should attend to an on-board fire before acknowledging an ATC clearance, such as a speed reduction for aircraft spacing (i.e., a low priority task that is not immediately threatening).

Theoretical Constructs about TASKS:

T1. The automaticity of tasks determines the resource requirements.

T2. Tasks should be, to a large extent, performed in AP mode.

T3. Some tasks are not good candidates for automatization.

T4. The ANCS prioritization strategy is, in general, a good task prioritization approach.

T5. The ANCS prioritization strategy has shortcomings.

T6. Pilots do not always follow the ANCS prioritization strategy.

Task Environment

In both experiments (Chapters 4 and 5), while there were differences in the use of individual prioritization factors, there was consistency from scenario to scenario. In other words, whatever the pilot's specific prioritization vector was, he applied it consistently from situation to situation. This is supporting evidence that the prioritization strategy of a pilot is not a random phenomenon, but a mental process that is systematically applied to the prioritization of tasks, whether consciously or not.

While the experiments in the current research did not undertake specific training techniques, the literature reviewed in Chapter 3 indicate that voluntary control of attention is a trainable skill and can be improved through the use of techniques such as variable-priority training (Gopher, 1992) and augmented feedback (Navon and Gopher, 1979; Gopher, et al., 1982). This is support for the use of CTM facilitation systems, such as the AgendaManager (Funk, et al., 1997; Funk, et al., 1999) as training aids. This suggests that instead of CTM facilitation on the flight deck, CTM facilitation can be used to better train pilots in the skill of managing multiple, concurrent tasks.

Theoretical Constructs about TASK ENVIRONMENT:

TE1. Pilots consistently apply their task prioritization vector.

TE2. Training of attentional control can be accomplished through CTM facilitation.

Summary CTM Theory

The theoretical constructs presented in the previous section summarize the findings of the present research efforts. Alone, these theoretical constructs comprise an incomplete representation of the CTM process. In the present section, these constructs are combined with findings of previous works (see Chapters 2 and 3) to present an overall theory of CTM.

The CTM theory contains three main sections: general CTM theory, flight deck task environment theory and task prioritization theory. Table 6.1 summarizes general knowledge about CTM, which comes from the works of many authors, including Funk, Wickens, Gopher and Rogers. CTM theory specific to the flight deck task environment is summarized in Table 6.2. This part of the CTM theory is primarily from the experimental psychology domain with contributions from authors such as Schneider, Shiffrin, Wickens, Tenny and Pew. Finally, Table 6.3 presents theoretical details related to the prioritization of tasks. It is in this area that the findings of the current research have made specific contributions. These contributions to the task prioritization theory are presented in bold, italicized font in Table 6.3.

Final Comments

In conclusion, one thing is crystal clear: The task prioritization process is not yet fully understood. It is a complex cognitive function that uses not only environmental cues, but also internal knowledge representations that may be a function of a person's past experiences. To fully understand task prioritization may be to fully understand human cognition. Although science is not yet there, it is through the efforts of research, such as the current work, that new insights into these topics are discovered.

General CTM Theory	Justification	Source
CTM is a mental process by which pilots manage multiple, concurrent tasks	The performance of multiple tasks adds another management dimension to the performance of single tasks	Funk (1991); Wickens (1992)
A primary dimension of CTM is the voluntary control of attention	Experimental results from other research efforts	Gopher (1992)
Voluntary control of attention can be aided by augmented system feedback	Experimental results from other research efforts	Navon and Gopher (1979); Gopher, et al (1982)
Training of attentional control can be accomplished through augmented system feedback	Experimental results from other research efforts	Navon and Gopher (1979); Gopher, et al (1982)
CTM performance can be improved through CTM facilitation	Superior CTM performance using pilot aids in simulator studies	Funk and Lind (1992); Funk and Kim (1995); Funk, et al (1997)
CTM errors contribute, at least in part, to accidents and incidents	CTM errors are present in a significant number of aircraft accidents and incidents	Chou (1991); Madhavan (1993); Wilson (1998);
CTM can be divided into Strategic and Tactical Cockpit Task Management	Conceptual analysis and pilot interviews	Rogers (1996)
CTM is largely dependent on individual differences	**Simulator study results and analysis**	***Task prioritization experiment #2; Schutte and Trujillo (1996)***

Table 6.1 General CTM Theory.

Flight Deck Task Environment Theory	Justification	Source
Flight deck tasks are categorized into discrete, pre-planned tasks and continuous, repetitive tasks	Conceptual analysis and pilot interviews	Rogers (1996)
The automaticity of tasks determines their resource requirements	Automated tasks require less mental resources than tasks performed in controlled processing mode	Schneider and Shiffrin (1977); Wickens (1992)
Tasks should be, to a large extent, performed in AP mode	Automating tasks free mental resources so pilot can manage multiple, concurrent tasks	Wickens (1992); Damos (1991)
Some tasks are not good candidates for automatization	Specific task characteristics require controlled processing	Allport (1992); Tenny and Pew (1990); Norman (1988)

Table 6.2 Flight Deck Task Environment Theory.

Task Prioritization Theory	Justification	Source
Resource conflicts due to multiple, concurrent tasks are resolved using task prioritization	Humans can devote thoughtful, conscious attention to only one task at a time	Funk (1991); Adams and Pew (1990); Adams, et al (1991)
Scheduling of tasks is the dominant CTM processes	Conceptual analysis and pilot interviews	Rogers (1996)
CTM is time-driven	The overriding CTM process is scheduling or ordering of tasks	Rogers (1996)
Pilots are prone to prioritization errors in challenging situations	***9 performance errors in 24 scenarios***	***Task prioritization experiment #2***
Pilots would often change the task execution order when given the chance to retrospectively evaluate a situation	***Majority of subjects changed task execution order***	***Task prioritization experiment #2***
The ANCS prioritization strategy is, in general, a good task prioritization approach	Pilots very seldom make task prioritization errors with catastrophic results	Excellent aviation safety record
The ANCS prioritization strategy has shortcomings	***Specific situations require violation of ANCS strategy***	***Current research analysis***
Pilots do not always follow the ANCS prioritization strategy	***Pilots task execution order did not strictly adhere to the ANCS strategy***	***Task prioritization experiment #2; Schutte and Trujillo (1996)***

Table 6.3 Task Prioritization Theory.

Task Prioritization Theory - Continued	Justification	Source
CTM is composed of 2 activities: workload management and monitoring of the situation	Simulator study results and analysis	Schutte and Trujillo (1996)
Workload management and monitoring can be accomplished by: ANCS, perceived severity, procedure-based or event-driven strategies	Simulator study results and analysis	Schutte and Trujillo (1996)
Workload management is best performed using the perceived severity strategy	Simulator study results and analysis	Schutte and Trujillo (1996)
Monitoring is best achieved using the ANCS strategy	Simulator study results and analysis	Schutte and Trujillo (1996)
Task prioritization is performed by an evaluation of a vector of factors	Conceptual analysis	Gopher (1992); Adams and Pew (1990); Logan (1985)
Pilots do not all prioritize multiple, concurrent tasks in the same way	***Significant individual differences found***	***Task prioritization experiment #2***
Pilots consistently apply their task prioritization vector	***No statistical difference in use of factors between scenarios***	***Task prioritization experiment #2***
Status, Procedure and Value are primary factors that affect task prioritization	***Empirical results supported presence of factors***	***Task prioritization experiments #1 and #2***
Other prioritization factors may exist, but were not identified in the present study	***Limitations of research methods may fail to identify prioritization factors***	***Task prioritization experiments #1 and #2***

Table 6.3 Task Prioritization Theory - Continued

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APPENDICES

Appendix 1
Glossary

Accident – A catastrophic event in which substantial damage is sustained to an aircraft or human lives are lost.

Air Traffic Control – A system used to monitor and direct air traffic

ANCS – see Aviate-Navigate-Communicate-Manage Systems

ASRS – see Aviation Safety Reporting System

ATC – see Air Traffic Control

Attitude Indicator – A flight instrument that gives the pilot an indication of the attitude of the aircraft relative to its pitch and roll axes.

Aviate-Navigate-Communicate-Manage Systems – A classification system that establishes general rules for the prioritization of tasks on the flight deck. Aviate tasks have a higher priority than navigate tasks, which have a higher priority than communicate tasks, etc. It is a general framework taught early in training and well accepted in the aviation research community.

Aviation Safety Reporting System – A voluntary, confidential incident reporting system managed by NASA for the FAA.

Cockpit Task Management – In the context of the commercial flight deck, the function in which the human operator manages his/her available sensory and mental resources in a dynamic, complex, safety-critical environment in order to accomplish the multiple tasks competing for a limited quantity of attention.

CTM – see Cockpit Task Management

EICAS – see Engine Indication and Crew Alerting System

Engine Indication and Crew Alerting System – An electronic instrument system for modern turbine-powered aircraft that senses engine (and other) parameters and displays them on one of two multicolor display units on the instrument panel.

FAA – see Federal Aviation Administration

FAR – see Federal Aviation Regulations

Federal Aviation Administration – The body of the U.S. government with primary responsibility for safety in civil aviation.

Federal Aviation Regulations – Regulations established by the Federal Aviation Administration which govern the operation of aircraft, airways, and airmen. Compliance with FARs is mandatory.

ILS – see Instrument Landing System

Incident – In the context of aviation, an incident is the occurrence of a regulations violation or an unsafe situation that is rectified before a more critical situation develops.

Instrument Landing System – A special type of electronic guidance system used to allow aircraft to land when the ceiling and visibility are too low for a safe visual approach to the runway. An ILS is made up of four basic parts: the localizer, glide slope, marker beacons, and approach lights.

Localizer – The portion of an instrument landing system that directs the pilot of an aircraft down the center line of the instrument runway for the final approach in an instrument landing.

National Transportation and Safety Board – The agency responsible for investigating civil aviation accidents occurring in the U.S. and for providing U.S. Accredited Representatives to non-U.S. accident investigating boards when necessary. The NTSB also is responsible for issuing safety recommendations to the FAA aimed at preventing future accidents.

NTSB – see National Transportation Safety Board

Very-high frequency omnirange navigation equipment – A type of electronic navigation equipment in which the instrument on the flight deck identifies the radial, or line from the VOR station measured in degree clockwise from magnetic north, along which the aircraft is located.

VOR – see Very-high frequency omnirange navigation equipment

Appendix 2
Informed Consent Document for Experiment 1

Department of Industrial & Manufacturing Engineering
Oregon State University

INFORMED CONSENT DOCUMENT

I understand that I will participate in flight deck automation research conducted under the supervision of Dr. Ken Funk of the Industrial & Manufacturing Engineering Department. I understand that in this experiment I will use my aviation knowledge and skills to fly a computer-based, part-task flight simulator. After a half-hour training session I will fly a set of flight scenarios. The entire experiment should last no longer than two hours.

I am aware that this is an unpaid experiment. Although physiological risks during the experiment are minimal, I understand that I will experience a level of psychological stress comparable to that of playing a video game during the experiment. While the experiment is being run, the evaluator will videotape the flight operation and later ask questions for data collection purposes.

My identity will not be released to any other persons, organizations, or publications. All references to subjects in this study will be encoded and kept confidential, and all identity-related information (including videotapes) destroyed within three years of the experiment.

I understand that any questions concerning aspects or rights related to this experiment should be directed to Dr. Ken Funk at 541-737-2357. I understand that Oregon State University does not provide compensation or medical treatment in the event the subject is injured as a result of participation in this study.

I understand that participation is voluntary, and my refusal to participate will not result in penalties or loss of benefits that I am otherwise entitled. My signature below indicates that I have read and that I understand the procedures described above and give my informed and voluntary consent to participate in this study. I understand that I will receive a signed copy of this consent form.

______________________________ ____________________

Subject's Signature   Date Signed

____

Subject's Name

____

Subject's Phone Number

Appendix 3
Pre-Trial Questionnaire for Experiment 1

Name: ______________________ Age: ___ Subject #: ____

Current seat:
Captain
First Officer
Flight Engineer
Other: __________________

Current Aircraft Type Certificate: ___________________

Total Flying Time: ___________ Approximate Single-Pilot Time: _____

Approximate EFIS time: ____________

Certificates/Ratings:
Private
Instrument
Multi-engine
Commercial
CFI
ATP
Other: __________________

Have you recently taken any medication that is likely to affect your flying and decision-making skills?
No
Yes

Have you consumed an unusual amount of caffeine today?
No
Yes, *more* than usual
Yes, *less* than usual

Are there any circumstances today that might affect your ability to fly?
No
Yes

Appendix 4
Post-Trial Questionnaire for Experiment 1

Subject # _______

Did you receive adequate training to serve the purpose of this experiment, as you understand it? Explain.

Rate the overall difficulty of the flying in this experiment, as compared to your actual flying experience.

Much easier
Easier
Roughly equivalent
More difficult
Much more difficult

Please elaborate briefly:

What other comments do you have concerning the research or your experience with the experiment?

Finally, if you have any questions regarding the experiment, don't hesitate to ask the experimenter.

Appendix 5
Challenge Probe Point Questionnaires

Questionnaire for CPP-A:

At this point in the flight, there were at least the following 6 tasks active. Please list the order that you performed these tasks in from 1-6. Use the videotape to assist you if needed:

_____ configure panel for ILS

_____ turn to heading 240°

_____ respond to ATC clearance

_____ engine fire checklist

_____ initiate descent

_____ reduce speed

Other task(s) not listed: ____________________

Where does this task(s) fit in the order?:

On the next pages, there are 18 statements related to the order in which the above tasks were performed. For each statement, select the choice that is, in your opinion, the most accurate for the statement and situation. The choices are:

Strongly Agree
Agree
N/A – If the statement is not relevant to the situation or you neither agree nor disagree with the statement, select the N/A choice.
Disagree
Strongly Disagree

Additionally, you will be asked if your response to the statement was appropriate for the situation. In other words, in retrospect, was the decision you made a good one?

Please think carefully about each statement and answer as accurately as possible.

I initiated the turn to 240 when I did was because I judged it to be the task farthest from satisfactory completion. (A1-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I initiated the turn to 240 when I did was because it was consistent with standard operating procedures. (A1-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I initiated the turn to 240 when I did was because if I didn't, the consequences were worse than for the tasks I performed after initiating the turn. (A1-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I initiated the turn to 240 when I did was because I had less time to perform it than the tasks I performed after it. (A1-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I initiated the turn to 240 when I did was because the heading instruments caught my attention. (A1-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I initiated the turn to 240 when I did was because of the time and/or effort required to perform the turn. (A1-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

I responded to ATC when I did was because I judged it to be the task farthest from satisfactory completion. (A2-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I responded to ATC when I did was because it was consistent with standard operating procedures. (A2-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I responded to ATC when I did was because if I didn't, the consequences were worse than for the tasks I performed after responding. (A2-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I responded to ATC when I did was because I had less time to perform it than the tasks I performed after it. (A2-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I responded to ATC when I did was because the incoming ATC message caught my attention. (A2-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I responded to ATC when I did was because of the time and/or effort required to reply. (A2-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

I performed the engine fire checklist when I did was because I judged it to be the task farthest from satisfactory completion. (A3-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the engine fire checklist when I did was because it was consistent with standard operating procedures. (A3-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the engine fire checklist when I did was because if I didn't, the consequences were worse than for the tasks I performed after it. (A3-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the engine fire checklist when I did was because I had less time to perform it than the tasks I performed after it. (A3-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the engine fire checklist when I did was because the master warning light and EICAS message area caught my attention. (A3-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the engine fire checklist when I did was because of the time and/or effort required to perform it. (A3-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

After answering the questions on the previous pages and carefully thinking about this situation, would you change the order you performed these tasks? In other words, in your opinion, is there a more optimal order in which you could have performed these tasks?

____ No, same order, no changes. (If "no", then the questionnaire is complete.)

____ Yes, I would perform the tasks in the following order:

_____ configure panel for ILS

_____ turn to heading 240°

_____ respond to ATC clearance

_____ engine fire checklist

_____ initiate descent

_____ reduce speed

Please briefly explain why you decided to change the order you would perform the tasks:

Questionnaire for CPP-B:

At this point in the flight, there were at least the following 6 tasks active. Please list the order that you performed these tasks in from 1-6. Use the videotape to assist you if needed:

_____ low fuel checklist

_____ report FAF to tower

_____ bus tie contactor checklist

_____ final approach checklist

_____ track the ILS (Localizer and G/S)

_____ 270V DC circuit breaker checklist

Other task(s) not listed: ____________________

Where does this task(s) fit in the order?:

On the next pages, there are 18 statements related to the order in which the above tasks were performed. For each statement, select the choice that is, in your opinion, the most accurate for the statement and situation. The choices are:

Strongly Agree
Agree
N/A – If the statement is not relevant to the situation or you neither agree nor disagree with the statement, select the N/A choice.
Disagree
Strongly Disagree

Additionally, you will be asked if your response to the statement was appropriate for the situation. In other words, in retrospect, was the decision you made a good one?

Please think carefully about each statement and answer as accurately as possible.

The reason I tracked the ILS when I did was because I judged it to be the task farthest from satisfactory completion. (B1-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I tracked the ILS when I did was because it was consistent with standard operating procedures. (B1-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I tracked the ILS when I did was because if I didn't, the consequences were worse than for the tasks I performed after it. (B1-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I tracked the ILS when I did was because I had less time to perform it than the tasks I performed after it. (B1-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I tracked the ILS when I did was because flight instruments caught my attention. (B1-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I tracked the ILS when I did was because of the time and/or effort required to track it. (B1-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

The reason I reported the FAF to ATC when I did was because I judged it to be the task farthest from satisfactory completion. (B2-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I reported the FAF to ATC when I did was because it was consistent with standard operating procedures. (B2-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I reported the FAF to ATC when I did was because if I didn't, the consequences were worse than for the tasks I performed after it. (B2-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I reported the FAF to ATC when I did was because I had less time to perform it than the tasks I performed after it. (B2-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I reported the FAF to ATC when I did was because the task somehow caught my attention. (B2-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I reported the FAF to ATC when I did was because of the time and/or effort required to report it. (B2-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

The reason I performed the bus tie contactor checklist when I did was because I judged it to be the task farthest from satisfactory completion. (B3-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the bus tie contactor checklist when I did was because it was consistent with standard operating procedures. (B3-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the bus tie contactor checklist when I did was because if I didn't, the consequences were worse than for the tasks I performed after it. (B3-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the bus tie contactor checklist when I did was because I had less time to perform it than the tasks I performed after it. (B3-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the bus tie contactor checklist when I was because the master warning light and EICAS message area caught my attention. (B3-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I performed the bus tie contactor checklist when I did was because of the time and/or effort required to perform it. (B3-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

After answering the questions above and carefully thinking about this situation, would you change the order you performed these tasks? In other words, in your opinion, is there a more optimal order in which you could have performed these tasks?

____ No, same order, no changes. (If "no", then the questionnaire is complete.)

____ Yes, I would perform the tasks in the following order:

_____ low fuel checklist

_____ report FAF to tower

_____ bus tie contactor checklist

_____ final approach checklist

_____ track the ILS (Localizer and G/S)

_____ 270V DC circuit breaker checklist

Please briefly explain why you decided to change the order you would perform the tasks:

Questionnaire for CPP-C:

At this point in the flight, there were at least the following 5 tasks active. Please list the order that you performed these tasks in from 1-5. Use the videotape to assist you if needed:

_____ stop descent (level off)

_____ monitor/reduce airspeed

_____ turn onto the localizer

_____ respond to ATC instruction

_____ attend to the master warning light

Other task(s) not listed: ____________________

Where does this task(s) fit in the order?:

On the next pages, there are 18 statements related to the order in which the above tasks were performed. For each statement, select the choice that is, in your opinion, the most accurate for the statement and situation. The choices are:

Strongly Agree
Agree
N/A – If the statement is not relevant to the situation or you neither agree nor disagree with the statement, select the N/A choice.
Disagree
Strongly Disagree

Additionally, you will be asked if your response to the statement was appropriate for the situation. In other words, in retrospect, was the decision you made a good one?

Please think carefully about each statement and answer as accurately as possible.

The reason I leveled off when I did was because I judged it to be the task farthest from satisfactory completion. (C1-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I leveled off when I did was because it was consistent with standard operating procedures. (C1-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I leveled off when I did was because if I didn't, the consequences were worse than for the tasks I performed after it. (C1-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I leveled off when I did was because I had less time to perform it than the tasks I performed after it. (C1-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I leveled off when I did was because the call from ATC caught my attention. (C1-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I leveled off when I did was because of the time and/or effort required to perform it. (C1-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

The reason I turned onto the localizer when I did was because I judged it to be the task farthest from satisfactory completion. (C2-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I turned onto the localizer when I did was because it was consistent with standard operating procedures. (C2-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I turned onto the localizer when I did was because if I didn't, the consequences were worse than for the tasks I performed after it. (C2-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I turned onto the localizer when I did was because I had less time to perform it than the tasks I performed after it. (C2-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I turned onto the localizer when I did was because flight instruments caught my attention. (C2-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I turned onto the localizer when I did was because of the time and/or effort required to turn onto it. (C2-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

The reason I was trying to figure out why the master warning light was flashing when I did was because I judged it to be the task farthest from satisfactory completion. (C3-1)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I was trying to figure out why the master warning light was flashing when I did was because it was consistent with standard operating procedures. (C3-2)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I was trying to figure out why the master warning light was flashing when I did was because if I didn't, the consequences were worse than for the tasks I performed after it. (C3-3)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I was trying to figure out why the master warning light was flashing when I did was because I had less time to perform it than the tasks I performed after it. (C3-4)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I was trying to figure out why the master warning light was flashing when I did was because the master warning light caught my attention. (C3-5)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:
The reason I was trying to figure out why the master warning light was flashing when I did was because of the time and/or effort required to do it. (C3-6)	Strongly Agree Agree N/A Disagree Strongly Disagree	Was this appropriate? Yes / No	Additional Comments:

After answering the questions above and carefully thinking about this situation, would you change the order you performed these tasks? In other words, in your opinion, is there a more optimal order in which you could have performed these tasks?

____ No, same order, no changes. (If "no", then the questionnaire is complete.)

____ Yes, I would perform the tasks in the following order:

_____ stop descent (level off)

_____ monitor/reduce airspeed

_____ turn onto the localizer

_____ respond to ATC instruction

_____ attend to the master warning light

Please briefly explain why you decided to change the order you would perform the tasks:

Appendix 6
Informed Consent Document for Experiment 2

Department of Industrial & Manufacturing Engineering
Oregon State University

INFORMED CONSENT DOCUMENT

I understand that I will participate in flight deck automation research conducted under the supervision of Dr. Ken Funk of the Industrial & Manufacturing Engineering Department. I understand that in this experiment I will use my aviation knowledge and skills to fly a computer-based, part-task flight simulator. After a half-hour training session I will fly a set of flight scenarios. The entire experiment should last no longer than five hours.

Although physiological risks during the experiment are minimal, I understand that I will experience a level of psychological stress comparable to that of playing a video game during the experiment. While the experiment is being run, the evaluator will videotape the flight operation and later I will fill out a questionnaire for data collection purposes.

My identity will not be released to any other persons, organizations, or publications. All references to subjects in this study will be encoded and kept confidential, and all identity-related information (including videotapes) destroyed within three years of the experiment.

I understand that any questions concerning aspects or rights related to this experiment should be directed to Dr. Ken Funk at 541-737-2357. I understand that Oregon State University does not provide compensation or medical treatment in the event the subject is injured as a result of participation in this study.

I understand that participation is voluntary, and my refusal to participate will not result in penalties or loss of benefits that I am otherwise entitled. My signature below indicates that I have read and that I understand the procedures described above and give my informed and voluntary consent to participate in this study. I understand that I will receive a signed copy of this consent form.

____________________________________ ______________________
Subject's Signature Date Signed

____
Subject's Name

____
Subject's email Address (or phone number)

Appendix 7
Pre-Trial Questionnaire for Experiment 2

Pilot Background Questionnaire

Name: ________________________ Age: _____ Subject #: _____

Current seat:
Captain
First Officer
Other: ____________________

Current Aircraft Type Certificate: ____________________

Total Flying Time: ____________ Approximate Single-Pilot Time: _____

Approximate EFIS "Glass cockpit" time: ____________

Certificates/Ratings:
Private
Instrument
Multi-engine
Commercial
CFI
ATP
Other: ____________________

Have you recently taken any medication that is likely to affect your flying and decision-making skills?
No
Yes

Have you consumed an unusual amount of caffeine today?
No
Yes, *more* than usual
Yes, *less* than usual

Are there any circumstances today that might affect your ability to fly?
No
Yes

Appendix 8
Simulator Training Syllabus

Simulator Training:

General Intro. to the displays:

- General description of the displays
- Explain how they have to use two mice and that will take getting use to.
- Only 1 VOR for navigation

Initial Aircraft Control:

- Start the sim with the exp2.dat and let them maintain altitude.
- Explain the Flight Director command bars
- Do some banks to headings (while still heading away from ECA).
- Explain the VOR and controls.
- Dial in OAK VOR and track to it.
- Explain the ALT BUG and descents (V/S mode, V/S rate)
- Descent rate is 1000'/min. This is the desired rate of descent. 1500'/min. would be considered extreme and 2000'/min. is considered unsafe for this aircraft.
- Descend down to 1800'. When an altitude assignment is given, fly it within +/- 100', just as the FARs specify.
- Climb back to 6000'
- Level off and maintain 6000'
- Give speed settings. Explain speed limitations: 250 kts. under 10,000';

Intercepting the localizer and glide slope:

- Start the sim with the "final.dat" scenario.
- Specs: at 1800', DME 18 from SFO, on 240 heading, speed 205, flaps 15 (you need to configure the ILS stuff)
- Explain the general idea. Explain what the "app" button does.
- Explain the mode annunciation on the pfd
- Have them memorize the procedure to configure for the ILS
- Run through the scenario until they get it. (Twice?)

Introduction to scenario:

- Start the sim with the "exp2.dat and explain the scenario (using the low alt. chart). No speed modifications on this scenario.
- Give initial clearance:
  "OSU 123, cross SUNOL at 6000'. After SUNOL, descend to 4000', turn right heading 240° vector for the ILS.
- Make sure they make the turn at SUNOL.
- At DME 20:
  "OSU123, Descend to 1800', cleared for the ILS, report BRIJJ to tower on 119.0"
- Make sure they report the FAF
- Terminate at the IM.

Configuration for landing:

- There are two checklists to be performed.
- The arrival/descent checklist can be performed whenever you want.
- The final approach checklist should be performed after gear down. This should occur at the FAF. So: At BRIJJ, Gear Down -> final approach checklist.
- You should be at 165 at the FAF (BRIJJ).
- The placard on the monitor shows the flaps speeds. You should be at or below the speeds before setting the flaps. Gear down is below 180 kts. and landing speed is 150 kts. Aircraft limitation is +20 kts. over flap speed settings. DO NOT EXCEED FLAP SPEED LIMITATIONS.
- Reset the "exp2.dat" scenario and let them run it. Standard clearances.
- Go again if necessary

System Faults:

- Start the sim with the "exp2.dat" scenario. Start it and put it on autopilot.
- Read through malfunction docs. with subject. Explain the significance of each malfunction.
- These must all be memory items, so we will practice until you can do them all from memory.
- Introduce all malfunctions and have them practice them, until they can do them from memory. Freeze the sim and talk about each one in detail from the system sheets.
- Engine fire will be most difficult. After shutting down engine, let them get used to flying with only one engine. Fly for a while on a single engine, turns, descents, etc.

(about 2.5 hours to here)

Fly3-4 Scenarios with Malfunctions:

- Make sure to do an engine out on the 240° leg.
- Do some stuff on final
- Take notes and give them feedback as necessary after each flight is over.

Give Final Instructions:

- If anything unusual happens during the next four flights, handle it as best as you can, but try to handle it as you would in actual operation.
- You will be flying in the San Francisco class B airspace. You should fly according to all the FARs that you would if you were to actually operate in this airspace.
- If you need to call off an approach or request something from ATC, go ahead and do it. I will attempt to fill the role of ATC.
- I'm looking for you to behave as you would while flying. Don't try to give me what I expect, just try to fly as you would normally.

Appendix 9
Task Performance Errors

A conservative approach was taken to define what constitutes a performance error. The basis of these definitions lies in either the Federal Aviation Regulations or in situations with obvious safety implications. These criteria were specifically explained to the subjects during training.

Fail to Perform Fuel Crossfeed Task – A warning indicator alerting the pilot to a low fuel condition in the left tank was to be corrected by performing a fuel crossfeed from the right fuel tank. At the outset of this situation, less than 100 lbs. of fuel was available for the left engine. Approximately 2 minutes of fuel was available before the left tank would empty, stalling the left engine. Failure to perform this task was determined to be an error.

Altitude Error – A deviation in the altitude of more than +/- 200' from the ATC-assigned altitude. FARs specify this deviation to be +/- 100 feet.

Speed Error – A significant speed deviation in one of the following categories: (1)More than +20 kts. over the flap setting speed (safety consideration due to limitations of the aircraft). (2)Exceed 250 kts. under 10,000' (A FAR limitation).

Failure to Comply with ATC Vector – Failure to initiate turn within 2 miles of an ATC clearance. (A FAR limitation).

Descent Rate Error – Descents were occur at a rate of 1000'/min. A descent rate in excess of 2000'/min. was determined to be an error (safety consideration due to aircraft limitations).